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Evaluation and Development of Electric Vehicles

Summary Report

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August 1982

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EVALUATION AND DEVELOPMENT OF ELECTRIC VEHICLES

SUMMARY REPORT

by

DSMA ATCON LTD.
Toronto, Ontario.

August 1982

Transport Canada Transports Canada
Library and Documentation Centre
Centre de Documentation
Ottawa, Canada K1A 0N5

The contents of this report reflect the views of the contractor and not necessarily the official views or policies of the Transportation Development Centre.

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17. Abstract

A program for the evaluation and development of electric vehicles was sponsored by the Transportation Development Centre to evaluate the potential of electric road vehicles as a transportation alternative that could reduce Canada's current heavy dependence upon liquid petroleum fuels. DSMA ATCON Ltd. was program manager and principal investigator. Marathon Electric Vehicle Inc.was the fleet vehicle supplier and The Seaway Transport Canada was the fleet operator.

The largest task was the procuring, outfitting, supporting and monitoring of a demonstration fleet of 7 electric vans (Marathon C-360). The performance of the vehicles in service was monitored over a period of one year. During some 18,248 km of operation they were shown to have successfully replaced a fleet of petroleum-fueled vehicles. They were found to have a daily range of 50 km with charging during the day, a top speed of 60 km/h, compatibility with other traffic, and an availability record of 94%. A prototype parallel hybrid version of the C-360 was also evaluated. It had a faster acceleration, and greater top speed and range than the electric C-360. A number of components were tested using a laboratory test rig and alternative vehicle configurations were studied with the aid of the ELVEC computer program.

A number of conclusions were found. The electric vehicle did have the potential for reducing petroleum fuel consumption, although the Marathon C-360 was still in an early state of development. Hybrid vehicles had a short term potential for greater market penetration, and hence petroleum substitution, than all-electrics, but were a few years behind all-electrics in their development. It was found that many major components used in these vehicles had to be imported into Canada, were not fully state-of-the-art and did not form a properly matched system. Theoretical studies confirmed the fuel substitution potential for electric and hybrid vehicles but showed the maximum substitution in the area of commercial delivery vehicles would be achieved through the use of an improved electric van supplemented occasionally by a petroleum-fueled van.

Further electric vehicle demonstrations are recommended, including a continuation of the one at the Seaway. A component development program is also recommended. Immediate C-360 improvements should be directed at reliability as opposed to performance. Consideration should be given to development of an advanced microprocessor controlled electric van. A versatile electric and hybrid vehicle simulation program and thorough engineering and testing of a hybrid prototype are recommended.

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17 Résumé

Ce programme d'évaluation et de mise au point parrainé par le Centre de Développement des Transports avait pour objectif d'évaluer le potentiel des véhicules routiers électriques comme moyen de nous affranchir de notre assujettissement actuel aux carburants liquides tirés du pétrole.

Le maître d'oeuvre du programme, le fournisseur des véhicules électriques évalués et l'exploitant expérimental ont été respectivement DSMA ATCON LTD., Marathon Electric Vehicle Inc. et La Voie maritime Transports Canada.

Le gros du programme a consisté à organiser l'acquisition de l'équipement, le support logistique et le contrôle d'exploitation d'un parc expérimental de sept fourgonnettes électriques Marathon C-360. L'évaluation en service a porté sur une période d'un an au cours de laquelle les véhicules ont parcouru un total de 18,248 km et remplacé totalement le parc de camions à essence utilisés jusque-là. Elle a permis de dégager les points suivants: autonomie de 50 km moyennant rechargement des accumulateurs au cours de la journée, vitesse de pointe de 60 km permettant de s'intégrer sans problème dans la circulation et un taux de disponibilité de 94%.

Parallèlement, un prototype hybride - moteurs électrique et à essence montés en parallèle - a aussi été évalué. Il présente une meilleure accélération, une vitesse de pointe plus élevée et une autonomie plus grande que le Marathon C-360 dont il est issu. Le programme comportait également l'essai en laboratoire de certains composants et l'étude théorique de diverses variantes de traction au moyen du programme informatique ELVEC.

Le rapport arrive à un certain nombre de conclusions. Par exemple,

- que les véhicules électriques constituent une solution d'avenir à la pénurie de pétrole, mais que le Marathon C-360 en est encore aux premiers stades de son développement;
- que les véhicules hybrides pourraient s'assurer dans l'avenir immédiat une plus grande part du marché que les tout électriques; qu'en conséquence, ils présentent une solution immédiate plus intéressante au problème de la pénurie de pétrole; mais qu'ils accusent quelques années de retard par rapport aux premiers.

Il souligne aussi que bon nombre des principaux composants de ces véhicules doivent être importés de l'étranger, qu'ils sont légèrement dépassés et qu'ils ne forment pas un tout bien constitué.

Les études théoriques confirment que ces véhicules, tant les électriques que les versions hybrides, permettent effectivement de réduire nos besoins pétroliers, mais elles indiquent que dans le domaine des services de livraison le gain maximum s'obtient par l'utilisation d'une fourgonnette électrique améliorée, remplacée par un véhicule à essence dans certains cas bien définis.

Le rapport recommande de poursuivre les expérimentations du véhicule électrique, y compris celles en cours à la Voie maritime; de lancer un programme de perfectionnement des composants et de faire porter les efforts d'amélioration du C-360 sur la fiabilité plutôt que sur les performances. Il suggère aussi d'étudier l'opportunité de développer une nouvelle génération de fourgonnettes électriques à commande assistée par micro-ordinateur. Enfin, il recommande de mettre au point un programme polyvalent de simulation pour l'étude de véhicules tant électriques que hybrides et de mener à terme l'étude technique et l'essai d'un prototype de véhicule hybride.

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The authors would also like to thank the staff of Marathon Electric Vehicles Inc. for their cooperation in the fleet demonstration project and during the hybrid vehicle evaluation.

The efforts of Mr. H. Walker of Ontario Hydro in providing in-service testing of the hybrid vehicle were appreciated.

FOREWORD

This project resulted from an unsolicited proposal entitled "Evaluation and Development of an Electrically Powered Vehicle", April 19, 1978, which was submitted to the Department of Supply and Services (DSS) Science Centre by DSMA ATCON LTD. The project was intended to evaluate the potential of electric road vehicles as a possible future transportation alternative which would reduce the current heavy dependence upon liquid petroleum fuel, and provide an opportunity for Canadian industry to develop advanced new products for this market.

An initial quantity of up to seven electric vehicles, as determined by the Scientific Authority, representing the best currently available Canadian technology, was to be demonstrated and evaluated in fleet service under actual operational conditions. In parallel, a program of electric vehicle research and development was to be initiated leading to a second demonstration of approximately seven vehicles, as determined by the Scientific Authority, incorporating significant technological improvements in about 3 years, and construction of one very advanced prototype vehicle in 4-5 years.

The project, which involved a cooperative effort by government, industrial and consulting groups, was carried out under the direction of Transport Canada's Transportation Development Centre (TDC). The operational testing would be in accordance with test procedures to be developed by DSMA ATCON LTD.

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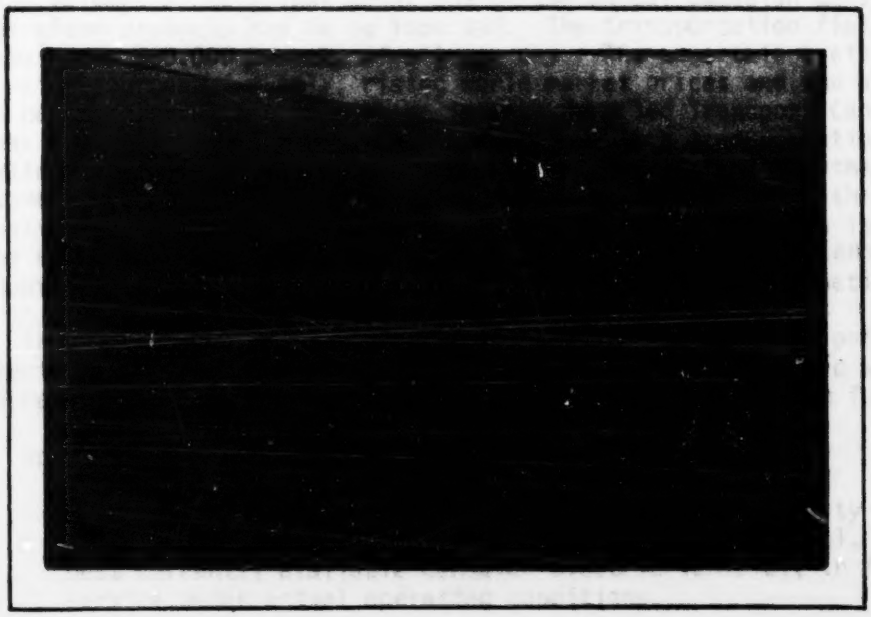

MARATHON C-360 FLEET AT THE SEAWAY

1. INTRODUCTION

1.1 Program Objectives

Although Canada has large deposits of oil in place, current production volumes dictate that about 20% of the annual Canadian consumption of petroleum products has to be imported. The transportation field alone consumes some 865,000 barrels of oil per day. The uncertain availability of foreign sources of supply, rising world market prices and the adverse trade balances resulting from these imports, have led Transport Canada to seek alternatives to non-renewable petroleum as a transportation fuel. One alternative is the use of electric motive power to replace the internal combustion engine in automotive vehicles. The program for the Evaluation and Development of Electric Vehicles reported herein is part of the continuing investigations being conducted by Transport Canada's Transportation Development Centre (TDC) to evaluate this alternative.

The overall objective of the program was to evaluate the potential of electric road vehicles as a future transportation alternative which would reduce our current heavy dependence upon liquid petroleum fuel.

Specific objectives of the program were as follows:

- to test and evaluate the Marathon C-360 electric utility van, produced by Marathon Electric Vehicles Inc. of Montreal, (the best currently available Canadian electric vehicle), in fleet service under actual operating conditions,

- to develop and evaluate an electric vehicle incorporating near-term technological improvements in about 2-3 years,

- develop and construct one prototype advanced technology electric vehicle in about 4-5 years,

- provide a focal point for component R & D in Canada, and to directly fund a portion of this work throughout the project.

1.2 Background

Early in 1977, a study into the use of electric vehicles (EVs) in Canada was conducted for Transport Canada (1). It showed that, although a number of Canadian organizations had investigated the use of electric vehicles, their efforts were uncoordinated and hampered by mechanical problems. Their vehicles were all imported, early production models, with poor service support.

A more extensive feasibility study was completed for Transport Canada later in the same year (2). This showed a growing, world-wide, interest in the redevelopment of electric vehicles for commercial use and the potential for an EV industry. This interest was generated by

concern over the Arab oil embargo, oil shortages and rising oil prices. The study indicated that there was a potential EV market in Canada, especially if the improvements promised in other programs materialized, but that Canadian industry was unlikely to benefit unless the Canadian government supported the development of an EV industry.

An unsolicited proposal submitted by DSMA ATCON LTD. (DSMA) April 19, 1978 addressed this topic. DSMA proposed a demonstration program, using the Marathon C-360 electric utility van, to gain experience in operating electric vehicles in Canada, and to serve as the focal point for an EV component development program. This proposal formed the basis for this program which was authorized on April 12, 1979.

In the meantime, The Seaway Transport Canada had initiated an evaluation of the suitability of electric vehicles for Seaway use. They examined the capability of small electric vans currently available in the terms of Seaway operations. A procurement competition was held and the Marathon C-360 selected. One vehicle was received in March 1979. The Seaway subsequently agreed to participate in the more extensive program managed by DSMA. The Seaway would act as the site operator for the demonstration project and integrate their vehicle into the program.

1.3 Program Participants

The scientific authority for the program was the Transportation Development Centre (TDC). A project officer from this organization was appointed to manage the project on behalf of TDC and to approve the work plan through contracts issued by the Department of Supply and Services (DSS).

A Steering Committee, composed of representatives from the Ministry of State for Science and Technology, the Department of Industry, Trade and Commerce, the Energy R & D Panel, DSS and TDC, was formed to counsel the project officer in the performance of his duties. DSMA, The Seaway, Marathon and additional government departments and agencies also participated in meetings of the Steering Committee, which were held at approximately six month intervals throughout the program, to consider progress and plan future activities.

The principal investigator was DSMA. They were responsible for the detailed planning and administration of the program; procurement, outfitting and repair of vehicles; collection, analysis and reporting of vehicle service and performance data; investigation of improved components, systems and configurations; and the definition and specification of product improvements.

The Seaway were the site operators of the first demonstration fleet. They were responsible for the day-to-day operation of the vehicles, routine maintenance activities, and cooperation with DSMA in the collection of operational and performance data.

Marathon Electric Vehicles Inc. supplied the vehicles for the demonstration fleet. They serviced the vehicles in accordance with warranty commitments, and were requested to advise and assist in pro-

curing improved components and to assist in the installation of product improvements as required. They were kept informed of events and results but, in general, were not expected to participate in the program in other ways.

1.4 Program Activities

The program began April 12, 1979 and the activities ended March 31, 1982. A fleet of seven electric vans was demonstrated, a hybrid prototype evaluated, various components evaluated, and theoretical studies conducted. In March 1981 the plans and objectives were revised as follows:

- the time frame was reduced from 4 or 5 years to 3 years,
- the demonstration program would be limited to the first year of operation at the Seaway,
- product improvements introduced into the Seaway fleet during service were considered to have transformed it into the improved fleet,
- no further product improvement activities would be conducted under this program,
- the prototype for the advanced vehicle would take the form of a parallel hybrid version of the Marathon C-360 (C-360).

Some evaluation of the original Seaway vehicle was conducted between March 1979 and the summer of 1980. This helped with the specification of the demonstration fleet which was ordered November 1979. The fleet vehicles were delivered to the DSMA laboratory during May and June of 1980 and outfitted for Seaway service in the following weeks. The demonstration period was officially September 18, 1980 to September 18, 1981. The vehicles have continued in service after this period and are planned to be used indefinitely but this program no longer monitors or services them.

The C-360 hybrid prototype was evaluated between November 1981 and March 1982.

An essential part of the work was range testing. In order to evaluate the vehicles from a user's point of view, more emphasis was placed on testing on public roads than on test tracks. This required the formulation and development of test methods by DSMA and the exercising of considerable judgement due to the many, often uncontrollable, variables. It is trusted that these methods will be a good basis for continuing EV R & D in Canada.

2. DESCRIPTION OF DEMONSTRATION AND TEST VEHICLES

2.1 Marathon C-360 Electric

2.1.1 Original Configuration

The first vehicle purchased by the Seaway (Seaway #148) and the demonstration fleet of seven vehicles were Marathon C-360 Electric Utility Vans as shown in Figure 1, and the frontispiece. They were supplied by Marathon Electric Vehicle Inc. of Montreal, Quebec.

As supplied by the manufacturer, the vans had a curb weight of 1474 kg (3250 lbs) and were rated to carry a driver, passenger and 227 kg (500 lbs) of cargo for a gross weight of 1837 kg(4050 lbs). A cargo space of 2.8 m^3 (100 ft^3) was provided.

The vehicles were equipped with 16 ESB EV-106 batteries powering a Baldor 8 hp series electric motor with a contactor-resistor type controller for voltage control. The drive system utilized a Pinto 4-speed manual transmission and a modified Dana rear axle. There was no clutch in the system and shifting was done with power removed from the motor. Other features included Michelin steel-belted radial tires, a Lester on-board ferro-resonant charger, an ESPAR gasoline heater and a 12 volt accessory battery. Twelve of the traction batteries are carried in a captive trailer supported by the two rear wheels of the vehicle. Table 1 contains further details.

Vehicle #148 was a pre-production version hand-built by Marathon. Minor defects were noted during the initial inspection and test periods and others developed during the first year of service. These included inadequacies in such things as sealing around windows and doors, cab heating, protection of electrical components and other areas from road spray, driver visibility, visibility of turn signals, and motor cooling.

The fleet vehicles were Marathon's first production run, also hand built with limited tooling. Some 28 product improvements, based on experience with #148, had been introduced for the fleet vehicles.

2.1.2 Data Acquisition System Installed

In view of the large amount of data that could be generated through the operation of seven vehicles, an efficient and versatile system for the collection and processing of data was desired. The system should free the drivers of data collection responsibilities, and should be able to function in short term dynamic test conditions as well as week long unattended logging duties. The data should be in a form permitting instantaneous readout as well as subsequent analysis manually or automatically. The power supply to the system must permit remote functioning in vehicles. When the market was reviewed in early 1979, there did not appear to be anything available in a compact fully-packaged form. A decision was therefore made to design and build a special data acquisi-

Figure 1 - Marathon C-360 Van, Seaway #148

Type of Vehicle	- Commercial Van
Curb Weight	- 3250 lbs (1475 kg), as delivered by Marathon
Gross Weight	- 4050 lbs (1839 kg), recommended by Marathon
Cargo Space	- 100 ft^3 (2.83 m^3)
Height	- 70 inches (1.78 m)
Length	- 151 inches (3.84 m)
Width	- 62 inches (1.57 m)
Ground Clearance	- 6 inches (0.152 m)
Battery Weight	- 1056 lbs (479 kg) of which 792 lbs (346 kg) rides in captive trailer
Special Instrumentation	- Ammeter, resistor in use light, Tripmeter
Doors	- 2 and double cargo door in rear
Turning Circle	- 33 ft (10.1 m)
Body	- Polyethylene-aluminum-polyethylene sandwich sheeting (Alucabond)
Frame	- Tubular Steel
Bumpers	- Steel
Heater	- ESPAR BN4

Table 1 - Marathon C-360 Specifications

tion system (DAS) based on available components and micro-processor equipment.

The DAS was designed and arranged as a group of modules positioned in available spaces in the vehicle. The main module is shown in Figure 2. It was mounted over the transmission for easy access. Other modules were the cassette recorder box, a charging unit, a vehicle interface unit, and sensors. Data was transcribed onto cassette tape in the vehicle and later written onto a disc by the DSMA mini-computer. Data was also printed as illustrated in Table 2.

The channels on the DAS included: charger input voltage, charger input power, motor current, battery voltage, seven temperature sensors, distance, velocity, vehicle identification, driver identification, mission identification, and gearbox and controller status. On most channels the accuracy and resolution was of the order of 2%. Generally speaking, the sensors could be interrogated every second or every minute.

The sensors, wiring harnesses and mounting provisions for the DAS were installed on all 7 fleet vehicles. However, there were commissioning delays and the system saw limited use. It was used in structured testing as well as weekly logging operations. The effort was directed towards keeping one system in a fleet vehicle at all times with tapes being changed every 7-10 days. More data was generated than could be reduced manually. Data reduction software was not written during the program, but this can yet be done.

The DAS can be really worthwhile in a situation where its capabilities can be fully exploited and the user is in a position to conduct extensive analysis of the data, and use this knowledge for significant vehicle improvement. It is believed the DAS will be needed for major vehicle development. Furtunately, Canada is now as well advanced in this area as any other country working on EV development.

2.1.3 Modification to Fleet Vehicles

A number of modifications were made to customize the vehicle to the Seaway needs or to improve performance. Some were implemented before the vehicles saw Seaway service and others during the year of demonstration. The demonstration was never halted because vehicles were modified one at a time. The modifications increased the vehicle curb weight from 1474 kg (3250 lbs) to 1715 kg (3780 lbs), or 16%, with the DAS weighing about 15 kg (33 lbs).

Before the vehicles were deployed, roof racks, safety screens behind the driver, equipment bin provisions, floor mats, floor glides, and a floor extension were added. A 550 volt charging system was installed requiring the addition of components such as a plug, fuse box, cable compartment, switch, indicating light, transformer, and safety interlock. The blower for the traction motor had its controls modified. A 200 A power fuse and an emergency use back-up solenoid were added. Holes were drilled in the driver's seat frame to permit better charger cooling.

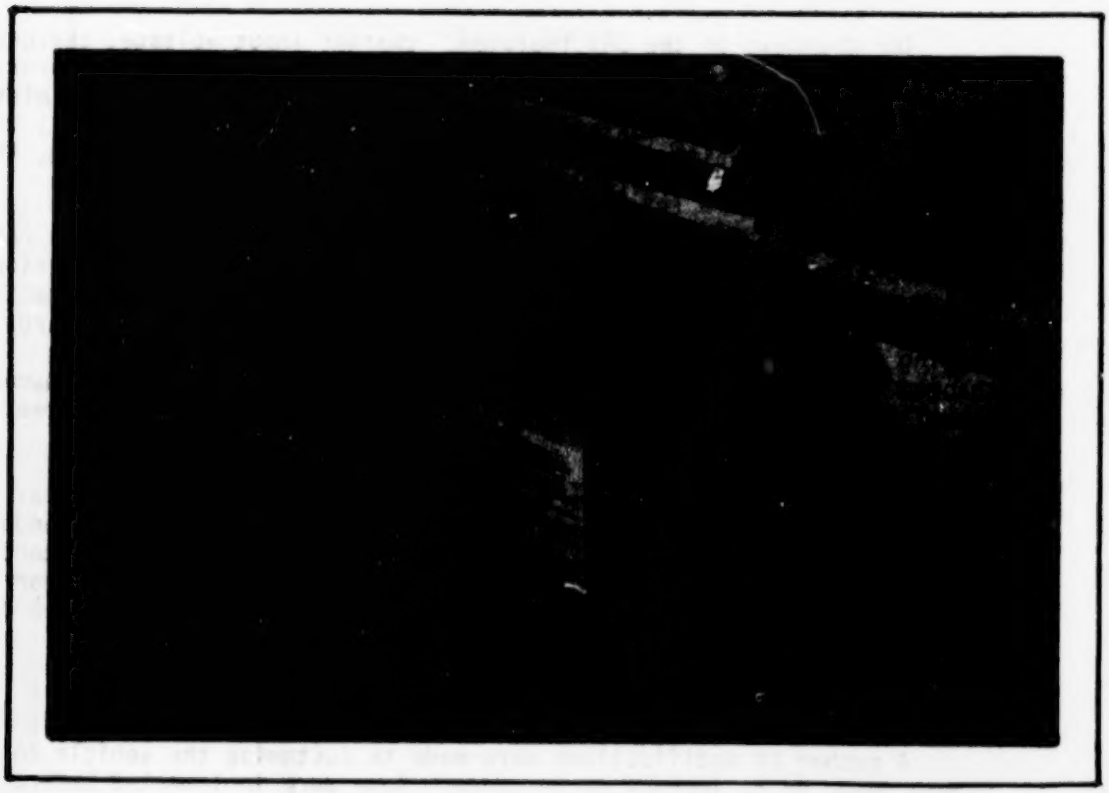

Figure 2 - DAS Main Module Mounted in a Vehicle

ELECTRIC VEHICLE PROGRAM - PERFORMANCE LOG

PAGE 4

16-MAR-1981

VEHICLE NO. 6

OPERATION MODE 0- PERFORMANCE CHECK

TIME	DIST	ID	MI	I	CH	G	C	SPEED	CHARGER		BATTERIES			MAIN COMP. TEMP.			2ND COMP.		AMB.	MOTOR REF	SYSTEM
	KM	#	#					KM/HR	VOLTS	WATTS	AMPS	VOLTS	WATTS	ENCL.	CELL1	CELL2	ENCL.	CELL1	TEMP.	TEMP. VOLTS	VOLTS
14:54:05	0.0	-1	-1	1	0	1	2	10.	0.	0.	134.	0.	0.	12.	15.	13.	13.	13.	11.	12. 5.080	5.011
14:54:06	0.0	-1	-1	1	0	1	2	14.	0.	0.	134.	0.	0.	12.	15.	13.	13.	13.	10.	12. 5.100	5.011
14:54:08	0.0	-1	-1	1	0	1	2	7.	0.	0.	118.	0.	0.	13.	15.	13.	13.	13.	10.	12. 5.100	5.011
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14:54:12	0.0	-1	-1	1	0	1	2	13.	0.	0.	102.	0.	0.	12.	15.	13.	13.	13.	10.	12. 5.100	5.011
14:54:14	0.1	-1	-1	1	0	1	2	9.	0.	0.	99.	0.	0.	12.	15.	13.	13.	13.	9.	12. 5.100	5.011
14:54:15	0.1	-1	-1	1	0	1	2	12.	0.	0.	87.	0.	0.	12.	15.	13.	13.	13.	9.	12. 5.100	5.011
14:54:16	0.1	-1	-1	1	0	R	1	17.	0.	0.	91.	0.	0.	12.	15.	13.	13.	13.	9.	12. 5.100	5.011
14:54:17	0.1	-1	-1	1	0	1	2	9.	0.	0.	91.	0.	0.	12.	15.	13.	13.	13.	9.	12. 5.100	5.011
14:54:19	0.1	-1	-1	1	0	1	2	10.	0.	0.	87.	0.	0.	12.	15.	13.	13.	13.	9.	12. 5.100	5.011
14:54:20	0.1	-1	-1	1	0	1	2	10.	0.	0.	91.	0.	0.	12.	15.	13.	13.	13.	9.	12. 5.100	5.011
14:54:21	0.1	-1	-1	1	0	1	2	18.	0.	0.	83.	0.	0.	12.	15.	13.	13.	13.	9.	12. 5.100	5.011
14:54:22	0.1	-1	-1	1	0	1	2	17.	0.	0.	75.	0.	0.	12.	15.	13.	13.	13.	9.	12. 5.100	5.011
14:54:24	0.1	-1	-1	1	0	1	1	15.	0.	0.	47.	0.	0.	12.	15.	13.	13.	13.	8.	12. 5.100	5.011
14:54:25	0.1	-1	-1	1	0	1	0	10.	0.	0.	0.	0.	0.	12.	15.	13.	13.	13.	8.	12. 5.100	5.011
14:54:26	0.1	-1	-1	1	0	1	0	11.	0.	0.	0.	0.	0.	12.	15.	13.	13.	13.	8.	12. 5.040	5.011
14:54:27	0.1	-1	-1	1	0	1	0	8.	0.	0.	0.	0.	0.	12.	15.	13.	13.	13.	8.	12. 5.100	5.011
14:54:28	0.1	-1	-1	1	0	N	0	5.	0.	0.	0.	0.	0.	12.	15.	13.	13.	13.	8.	12. 5.100	5.011
14:54:30	0.1	-1	-1	1	0	1	0	6.	0.	0.	0.	0.	0.	12.	15.	13.	13.	13.	8.	12. 5.100	5.011
14:54:31	0.1	-1	-1	1	0	1	1	11.	0.	0.	95.	0.	0.	12.	15.	13.	13.	13.	8.	12. 5.100	5.011
14:54:32	0.1	-1	-1	1	0	1	1	4.	0.	0.	87.	0.	0.	12.	15.	13.	13.	13.	8.	12. 5.100	5.011
14:54:33	0.1	-1	-1	1	0	1	2	14.	0.	0.	225.	0.	0.	12.	15.	13.	13.	13.	8.	12. 5.100	5.011
14:54:35	0.1	-1	-1	1	0	1	2	15.	0.	0.	150.	0.	0.	12.	15.	13.	13.	13.	8.	12. 5.100	5.011
14:54:36	0.1	-1	-1	1	0	1	2	9.	0.	0.	102.	0.	0.	12.	15.	13.	13.	13.	7.	12. 5.100	5.011
14:54:37	0.1	-1	-1	1	0	1	2	11.	0.	0.	87.	0.	0.	12.	15.	13.	13.	13.	7.	12. 5.100	5.011
14:54:38	0.1	-1	-1	1	0	1	2	17.	0.	0.	83.	0.	0.	12.	15.	13.	13.	13.	7.	12. 5.100	5.011
14:54:39	0.1	-1	-1	1	0	1	2	11.	0.	0.	83.	0.	0.	12.	15.	13.	13.	13.	7.	12. 5.100	5.011
14:54:41	0.1	-1	-1	1	0	1	0	8.	0.	0.	0.	0.	0.	12.	15.	13.	13.	13.	7.	12. 5.100	5.011
IGNITION TURNED OFF																					
IGNITION TURNED ON																					
14:55:25	0.2	-1	-1	1	0	N	1	0.	0.	0.	47.	0.	0.	10.	14.	13.	13.	13.	6.	12. 5.100	5.009
14:55:26	0.2	-1	-1	1	0	N	0	0.	0.	0.	0.	0.	0.	10.	15.	13.	13.	13.	6.	12. 5.080	5.050
14:55:27	0.2	-1	-1	1	0	N	0	0.	0.	0.	0.	0.	0.	10.	15.	13.	13.	13.	6.	12. 5.100	5.050
14:55:29	0.2	-1	-1	1	0	N	0	0.	0.	0.	0.	0.	0.	10.	14.	13.	13.	13.	6.	12. 5.100	5.050
OPERATOR AND MISSION - IDENT ENTERED																					
14:55:30	0.2	11	22	1	0	N	0	0.	0.	0.	0.	0.	0.	10.	15.	13.	13.	13.	6.	12. 5.100	5.050
14:55:31	0.2	11	22	1	0	N	0	0.	0.	0.	0.	0.	0.	10.	15.	13.	13.	13.	6.	12. 5.080	5.050
14:55:33	0.2	11	22	1	0	N	0	0.	0.	0.	0.	0.	0.	10.	15.	13.	13.	13.	6.	12. 5.100	5.050
14:55:34	0.2	11	22	1	0	N	0	0.	0.	0.	0.	0.	0.	10.	15.	13.	13.	13.	6.	12. 5.100	5.050
14:55:35	0.2	11	22	1	0	N	0	0.	0.	0.	0.	0.	0.	10.	15.	13.	13.	13.	6.	12. 5.080	5.011
14:55:36	0.2	11	22	1	0	2	0	0.	0.	0.	0.	0.	0.	10.	15.	13.	13.	13.	6.	12. 5.100	5.011
14:55:37	0.2	11	22	1	0	1	1	2.	0.	0.	150.	0.	0.	10.	15.	13.	13.	13.	6.	12. 5.100	5.011
14:55:39	0.2	11	22	1	0	1	1	2.	0.	0.	118.	0.	0.	10.	15.	13.	13.	13.	6.	12. 5.100	5.011
14:55:40	0.2	11	22	1	0	1	1	2.	0.	0.	99.	0.	0.	10.	15.	13.	13.	13.	6.	12. 5.080	5.011
14:55:41	0.2	11	22	1	0	1	2	8.	0.	0.	144.	0.	0.	10.	15.	13.	13.	13.	6.	12. 5.100	5.011
14:55:42	0.2	11	22	1	0	1	2	17.	0.	0.	102.	0.	0.	10.	15.	13.	13.	13.	6.	12. 5.100	5.011

Table 2 - Typical DAS Printout

After the fleet was deployed at the Seaway, an extra grounding lead was installed. A battery heating system involving thermal insulation, AC powered strip heaters, and a control system was installed. The traction motor was modified to improve the cooling effectiveness of the forced air system. A fan was installed to further improve the charger cooling. The back-up solenoid system added to the controller proved ineffective as a means of emergency shut-down and was replaced by a more appropriate emergency disconnect switch mounted beside the driver. The ignition and blower relays proved to be underrated and were replaced by heavier units plus circuit modifications. The gasoline heater/defroster system was changed from a one-way air flow arrangement to a recirculation one in response to complaints of inadequate capacity. Other heating system changes were implemented to solve problems of improper shut-down sequencing, difficulty in filling the tanks, and vapour locks. To improve the weather sealing around the side doors, special kits were installed.

2.2 AM General Electruck

Two used AM General Electrucks with very low mileage were obtained in the fall of 1979. The vehicles were based on the AMC Jeep with a Gould electric propulsion system comprising a 20 hp Gould DC compound electric motor, a Gould 54 volt lead-acid battery (330 Ah rating) and a Gould SCR chopper. The curb weight was listed as 1644 kg with a 315 kg payload capacity. During the program Varta P125, ESB EV-106, and Chloride industrial batteries were used in the Jeeps.

2.3 Marathon C-360 Hybrid Prototype

This vehicle was basically a C-360 with a modified power plant. The curb weight was 1660 kg (3653 lbs). The hybrid van utilized the parallel operating configuration. The power consisted of a Briggs and Stratton 13.4 kW gasoline engine connected through a centrifugal clutch to an 8 kW (10.7 hp) Baldor series electric motor which was coupled to a Volvo 4-speed manual gearbox and the rear drive axle. Wheels and brakes were from a Ford Pinto, and Varta P125x lead-acid batteries were used.

Instrumentation on the vehicle included the Data Acquisition System (DAS), ammeter, and cylinder head temperature gauges. The vehicle was controlled by one foot pedal which was mechanically linked to the heat engine carburetor and the chopper. A mode switch allowed selection of electric, hybrid or gasoline only operation.

Problems occurred with licensing the vehicle, the battery charger, the one-way clutch, 12 V service battery and the use of the internal combustion engine (ICE) mode of operation. Most were solved satisfactorily before the vehicle was tested.

3. FLEET DEMONSTRATION PROJECT

3.1 Project Outline

The demonstration project was intended to define the current state-of-the-art of electric vehicle technology in Canada. A fleet of electric vehicles was to be operated in a realistic service environment to determine the level of support required and to define the level of serviceability and maintainability to be expected.

A fleet of C-360s was placed in service at the Seaway. Five were assigned to Seaway personnel to be used as transportation in the performance of their duties in the maintenance of equipment at the Welland Canal. The vehicles replaced 5 ICE vehicles. A sixth vehicle was held as a spare. A seventh vehicle was held by DSMA as a reference vehicle and was used to investigate problems encountered by the fleet vehicles and to serve as additional back-up to the fleet. The six vehicles at the Seaway were rotated through the 5 duty cycles to achieve even usage. Different vehicles served as the reference vehicle during the year of demonstration, so all 7 actually accumulated about the same amount of usage.

The region serviced by the vehicles was between Lake Ontario and Lock 7. The service centre (overnight charging station) was located between these two points being 12.1 km from the lake and 2.4 km from Lock 7. The roads were generally paved but there were some gravel stretches. Elevations varied from 82 m above sea level at the lake to 125 m at the service centre and 174 m at Lock 7, for a total change of 98 m. This gave rise to grades such as 3% over 451 m and 6% over 150 m.

Three of the vehicles were used by electricians, 1 by labourers, and 1 by machinists. The labourers' and electricians' vehicles had heavy loads and frequent usage. The machinists' vehicle carried light loads and had infrequent usage.

The vehicles were operated during the hours of 8:00 a.m. to 4:00 p.m. Monday to Friday. At other times they were parked and plugged in at the charging station as shown in the frontispiece. During service, the vehicles were usually plugged in for charging at the work sites. The fact of always being parked and charged outdoors was a real world condition whose effect was to be evaluated and was an example of the "no pampering" philosophy.

The DAS was operated as much as possible in one vehicle at the Seaway. During the demonstration year some 28 tapes representing 17 weeks of vehicle usage were collected. This produced about 400 pages of data. While not all of this was valid data, there was a great deal of valuable information on component and system performance obtained.

3.2 Availability Record

During a full twelve months of operation at the Seaway, the seven vehicles used in fleet service logged a total of 18,245 km (11,337 miles), as shown in Table 3, for an average of 2607 km (1620 miles) per vehicle. The lowest distance per vehicle was 2174 km and the highest 3056 km.

During this period there were 1850 vehicle days of service available. Of these, 75 were lost due to repair action, 86 due to a modification project and 394.5 due to standby as the spare or the reference vehicle. This left 1294.5 vehicle days of actual use. An average vehicle averaged 14.1 km each day it was used.

With 75 vehicle days lost due to repair action, at least one vehicle was unserviceable and had to be replaced by the spare 5.7% of the time. The overall availability record of the vehicle therefore was about 94%. This does not account for time lost when vehicles were out of service for just a few hours at a time.

3.3 Maintenance Activities

A program for preventive maintenance was evolved over the year of demonstration. Defining the cost involved in maintaining a fleet of electric vehicles in the field was indeed one of the goals of the demonstration project. The Seaway assumed responsibility for mechanical maintenance, the maintaining of battery fluid levels, and the monitoring of battery specific gravities. DSMA were responsible for maintaining the electric systems.

DSMA staff were at the Seaway almost every week during the fall of 1980 because of the modification project. During these visits, electrical problems on the fleet vehicles were investigated and maintenance activities carried out so no structured maintenance schedules were used. During December and January there were fewer scheduled trips by DSMA personnel but a marked increase in electrical system failures. It was concluded that the high incidence of failures was due to the higher operating currents caused by the stiffer drive train in cold weather and by connectors vibrating loose. In February 1981 therefore, a maintenance schedule was introduced whereby the connectors to battery and contactor posts were cleaned and tightened on each vehicle at six weeks intervals.

Besides preventive maintenance activities there were about 117 significant repairs conducted during the demonstration. Sixty were mechanical in nature and 57 electrical. They were distributed fairly evenly amongst the 7 vehicles and over the 12 months. They created a mean distance between failure of about 162 ± 40 km. 23 incidents required towing in a vehicle. Besides these repairs, there were many attempts at aligning the front ends.

The mechanical failures of greatest note were: 6 heater malfunctions, 3 transmissions replaced, 1 rear axle pinion bearing replaced, 1 rear axle snapped at a weld from modification, 4 charging cable door failures, 7 550V charging plugs repaired, 4 wiper motors malfunctioned, and 3 windows broken.

VEHICLE NUMBER	DAYS AVAILABLE FROM DEPLOYMENT TO SEPT. 18, 1981 (1) (2)	DAYS NOT USED (2)				DAYS ACTUALLY USED (3)	UNAVAILABILITY: DAYS NOT USED DUE TO REPAIR / DAYS ACTUALLY USED %	TOTAL DISTANCE REPORTED km	AVERAGE DAILY USE: TOTAL DISTANCE / DAYS ACTUALLY USED
		DUE TO REPAIR	DUE TO MOD's PROGRAM	DUE TO BEING SPARE	DUE TO BEING REF. VEHICLE				
281	269	10	10	40 ½	0	208.5	4.8	2594	12.4
282	269	14	23	30 ½	0	201.5	6.9	2638	13.1
292	258	8 ½	9	46	27	167.5	5.1	2660	15.9
308	269	13	9	34 ½	42	170.5	7.6	2174	12.8
309	252	10	18	34	0	190	5.3	2850	15.0
310	264	14	8	41	0	201	7.0	3056	15.2
311	269	5 ½	9	18	81	155.5	3.5	2276	14.6
TOTALS	1850	75	86	244.5	150	1294.5	Avg. 5.7	18248	Avg. 14.1

(1) Deployment taken as the day after OSMA delivered the vehicles to The Seaway. Aug. 25 for 281,282,311,308; Sept. 1 for 310; Sept. 10 for 292, and Sept. 18 for 309, all 1980.

(2) Weekends and Statutory Holidays not included.

(3) Days available - days not used & days actually used.

Table 3 - Fleet Vehicle Utilization Record During Demonstration Year

The noteworthy electrical failures were: 1 controller failure resulting in a damaged traction motor, 6 18/12V solenoids burned out, 2 of the initially-installed cutout switches burned out, 12 cable or connector burnouts, 7 instances of charger output breakers opening before 550V transformer taps were changed, 11 6V batteries failed, several power solenoids in motor speed controller burned out, 2 charging cord door microswitches failed, 7 ignition circuit faults, and 1 power resistor failure.

It was not possible to maintain accurate records of the time spent separately in repair or maintenance efforts. In total, however, it is estimated that they averaged about 2 man-hours per vehicle per week plus any travel time. This level of activity is the main reason why there were only 75 vehicle days lost through unserviceability. Repair and maintenance activities were always given top priority.

3.4 Driveability and Driver Acceptance

The controller and motor used on the C-360 provided a jerky control characteristic. "Jack rabbit" starts were difficult to avoid, making parking in close quarters difficult. There was a reasonably good low speed acceleration but it faded as the top speed was approached. The short wheel-base and steering characteristics produce a reasonably manoeuverable vehicle at moderate speeds. The front end alignment was often poor and resulting in shimmy at high speed. A stiff suspension, noise, vibration, and a high stiff seat with a low back also contributed to driver fatigue.

There were 26 persons at the Seaway who operated the fleet vehicles, so during the year novice drivers were continually handling the vehicles. While some of the drivers and supervisors were initially enthusiastic about the program, most of them had a decidedly negative attitude. They were generally co-operative but tended to be critical of the vehicles and may not always have followed the recommended operating procedures.

They seemed to accept the differences in driving characteristics between these vehicles and an ICE vehicle but were critical of the jerky controller and vibrations. They found driver comfort, especially the seat, the position of the steering wheel and the visibility poor. The operation of the accessories, such as wipers, heaters, horns and lights, were the most frequent cause of complaints. The drivers were not happy with the smaller size and payload relative to the ICE vehicles replaced, but found them adequate. Some supervisors expressed concern about the limited range, but again the vehicles appeared to handle the tasks assigned.

4. EVALUATION OF ELECTRIC VEHICLES

4.1 Evaluation of Vehicle #148

Vehicle #148 was received in March 1979, and placed in service as a pool vehicle to be used for general duty transportation. The vehicle also served as additional back-up to the fleet.

It logged just over 6000 km (3733 miles) in about 30 months with an availability of 85%. There were about a dozen component failures. A solenoid failure led to a cut-out switch failure and a motor runaway, but the motor was not damaged. The rear axle bevel gears had to be replaced in August 1979 at 3385 km. In November 1979 at 4714 km they failed again and were replaced with a heavier duty unit. The charger overheated and was replaced at 4915 km. The 12V battery failed at 5330 km. Repairs were required to the horn, lights, wiper, and heater. A cracked windshield was replaced at 5560 km. There was a motor burn-out after a year of service. Some 6V batteries needed replacing. In January 1980, after ten had failed, the whole pack of ESB EV-106s were replaced with a pack of Varta P-125s.

During May and June 1979, DSMA conducted a series of preliminary tests with the van to gain familiarity with EVs. They showed that the vehicle could fulfil a useful role at the Seaway. The speedometer and odometer were found to be inaccurate and a Sangamo tachograph was installed to give accurate speed indication and a permanent record of vehicle utilization.

A series of 5 range tests were conducted during February and March 1980 with the Varta P-125s. The vehicle was fully loaded and operated on streets and roads at the Seaway. Conditions of roads, weather, grades, etc., were very much real-world. The range was found to vary nearly linearly from 19 km at -2°C average electrolyte temperature to 31 km at 26°C. To create warmer batteries for some of these tests, the vehicle was thermally soaked in a heated garage. Specific energy consumption varied from 1.38 to 0.77 kWh/km with increasing electrolyte temperature.

Motor input power was found to be 30 kW (40 hp) for short term peaks and 11 kW (15 hp) for extended periods of time. The motor was rated at only 6 kW (8 hp) continuous and this helped explain the burn-out which occurred after a year of service.

The fully loaded vehicle had a top speed of 50 km/h (30 m/h) with accelerations of: 0-20 km/h in 12 seconds, 0-30 km/h in 20 seconds, and 0-40 km/h in 22 seconds. Better performance had been reported by Marathon as a result of tests with lighter loading and warmer batteries.

The general reaction to 148 was favourable. It could perform the tasks required by the Seaway, the availability record was good, and the support provided by Marathon was excellent. The problems encountered appeared to be due to quality control and inexperience in the operation

of EVs rather than fundamental design defects. In retrospect, #148 appears to have shown a better service record than the supposedly improved fleet vehicles which followed. Factors which could have contributed to this include;

- vehicle #148 was primarily driven by management using the prescribed operating procedures,
- higher energy density batteries were incorporated after January 1980,
- the curb weight of the vehicle was about 240 kg (530 lbs) less than the fleet vehicles and it was usually driven lightly loaded,
- the vehicle was used less frequently than the fleet vehicles, especially during the year of fleet demonstration.

4.2 Evaluation of Fleet Vehicles

4.2.1 Baseline Tests

A series of baseline tests was conducted in the fall of 1980 on the paved, private service roads of a local race-track to establish typical accelerations and top speeds of the fleet vehicles outfitted for Seaway service and fully loaded to 2090 kg (4600 lbs). A fifth wheel and stop watch were used to find the speeds and accelerations. The DAS was used to establish coast-down and power required curves.

The top speed reached in gears 1, 2, 3 and 4 was 26, 40, 52 and 62 km/h respectively. The rate of acceleration was highly dependent on gear selection. Rates of 0-30 km/h in 8 seconds, 0-40 km/h in 12 seconds, and 0-50 km/h in 21 seconds could be achieved by starting in a high gear. However, this resulted in a high current draw and was considered to be hard on the vehicle and electrical components. Using all the gears as recommended for minimum power and energy consumption and maximum range, these rates increase to 10, 21 and 30 seconds respectively. An additional 27 seconds was required to increase the speed from 50 km/h to 60 km/h.

The velocity time profile generated during coast-down showed that 78 seconds were required for the vehicle to reach standstill from 57 km/h. This data was analyzed to produce the motor power required vs velocity curve. This curve indicates that the electric motor must deliver 10 kW of power to sustain a speed of 50 km/h and that this requirement increases rapidly above this speed. This is consistent with measurements taken on #148 and with theoretical studies on a similar vehicle made available by Briggs and Stratton.

The speedometers and odometers were found to be in error. A correction kit was supplied by Marathon but not installed during the program due to interference with the DAS.

4.2.2 Range Tests

Performance and range tests under typical service conditions were

conducted over a measured route at the Seaway. This route was about 3500 meters long, with five stops including two traffic lights. The road was paved and reasonably level except for a 2% grade over about 300 meters, and a gravel apron around the Lock 3 substation. The route was measured using a fifth wheel. A similar route was measured out on local streets adjacent to the DSMA laboratory in Mississauga.

Figure 3 shows a typical speed and battery power profile generated by the DAS. The maximum speeds reached are in the order of 60 km/h for about 30 seconds with an average speed of about 30 km/h. Speed was found to be about 5 km/h higher (10%) and power required about 2.5 kW less (-13%) when the vehicle was going down the 2% grade as compared to going up in the first half of the lap. For most of this driving, battery power was the same as motor power and the excess over motor rating can be seen.

The test range, to 80% depth of discharge, in the battery pack (84V under 75A draw) was consistently less than 30 km and half of this value for cold vehicles with cold batteries. 2-4 km could still be driven after the cutoff point but vehicle power was reduced and traffic compatibility was a problem.

The variation in range with battery temperature and vehicle weight is shown in Figure 4. Some of the higher battery temperatures were achieved by using the battery heating system, although this still left a cold vehicle with subsequent high powertrain losses. Note that the range only increased marginally for the loaded vehicles with warm batteries.

4.2.3 In-Service Performance

The vehicles regularly carried a driver, passenger and up to 227 kg (500 lbs) of equipment for a total payload of 400 kg (885 lbs) and a gross vehicle weight of 2115 kg (4673 lbs). They have carried loads totalling 600 kg (1323 lbs) for a gross vehicle weight of 2315 kg (5140 lbs). The vehicles therefore operated up to 25% above rated gross vehicle weight. No structural or mechanical problems were attributed to this condition. Reviewing the data generated by the DAS under normal Seaway operating conditions, it would appear that there are no typical driving patterns. Each crew was different, each day was different, and each trip was different. With mid-day charging a vehicle might go 50 km in one shift. Average distance logged was only 14 km per day. There were instances where the vehicle ran out of power on the road and had to be towed in. These were usually attributed to failure to plug in at the work site.

Ambient temperatures varied from a daily low of $-22^{o}C$ in winter to a daily high of $34^{o}C$ in summer. For over two weeks in January the temperature averaged $-12^{o}C$ and did not rise above $-2^{o}C$. Within a few days temperatures could vary by $32^{o}C$. No components overheated in the summer. The cold in winter, no doubt, lowered the range, but the vehicles appeared to do the job.

The field experience proved essential for exposing faults in the vehicles and generating service experience. It was found that many of

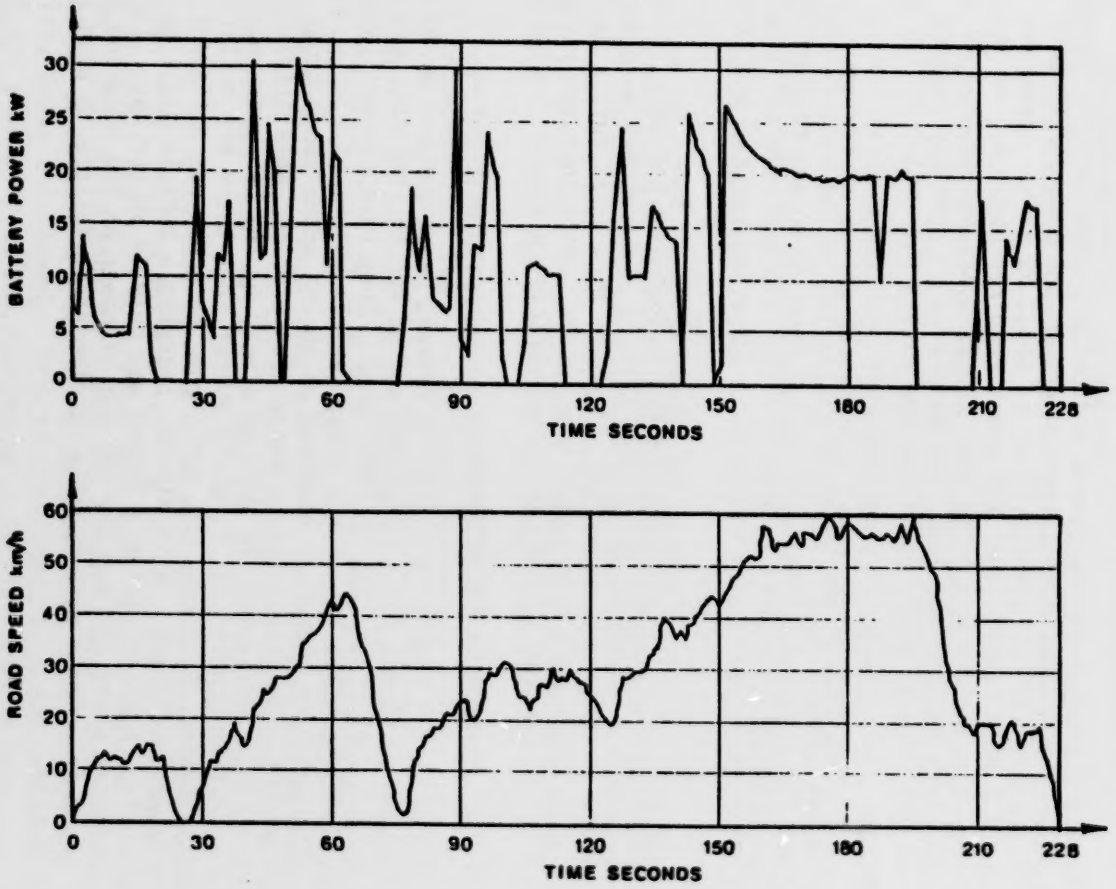

Figure 3 - Range Test - Fleet Vehicle #308 (November 16, 1980)
First Half of Lap (1.9 km) - Battery Power and
Vehicle Speed vs Time

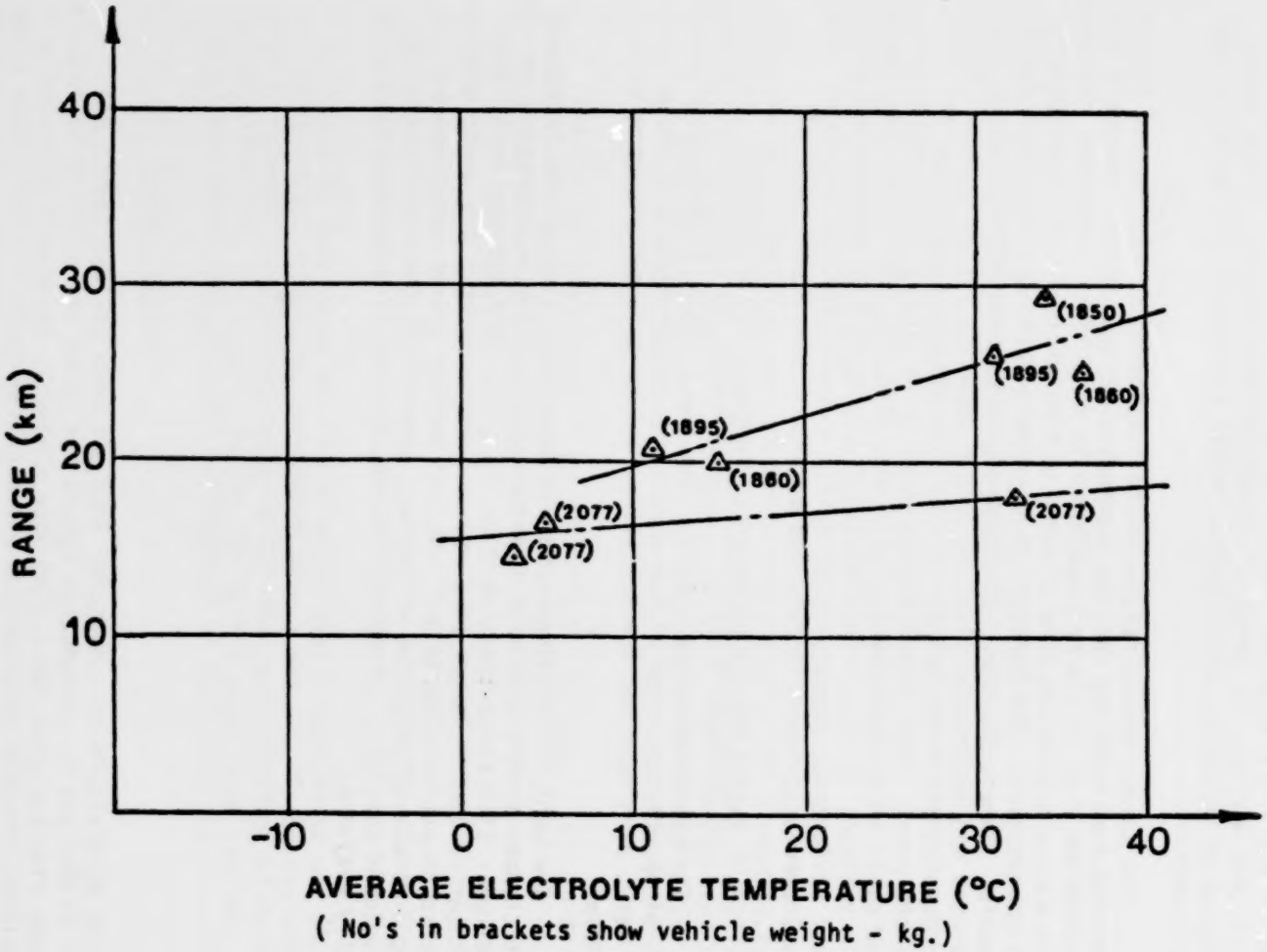

Figure 4 - Relationship of Range to Electrolyte Temperature for Fleet Vehicles

the repairs were simply and quickly executed. Others such as in the ignition or auxiliary circuits proved difficult to trouble-shoot due to inconsistent wiring. In terms of preventive maintenance, single point watering of batteries and a heavier rated electrical system would seem advantageous.

The Seaway demonstration can be considered an accelerated endurance test aimed at exposing vehicle weaknesses early. Range, endurance and performance data should be considered in this light. However, the operation does simulate the type of service that vehicles could encounter in the open market. The Marathon C-360 demonstrated that it could fulfil a useful commercial role. It successfully carried out all of the tasks assigned and replaced a fleet of larger capacity ICE vehicles. Admittedly the demonstration was set up to match the vehicle capability, but this was the point. The last 2 fleets tried in Canada were retired from service early in an atmosphere of failure. This program showed that the electric vehicle, in its current state of development in Canada, has sufficient performance capability to fulfil a useful role in industry. Further development, however, is required to extend this role.

4.3 Evaluation of AM General Electruck

The Electrucks were obtained for the purpose of gaining EV operational experience under winter conditions before deploying fleet vehicles, to serve as a test bed for batteries, and to gain experience with a chopper.

The vehicles received some use in pool service at the Seaway and the chopper system proved to provide much smoother acceleration and speed control. Five range tests were conducted by DSMA between April and October of 1980. Ranges of 24-42 km were obtained. The tests were conducted on public streets and involved various grades and stops per km, and 3 models of batteries of various usage histories. Both vehicles developed controller problems and were retired from service without being fully evaluated.

5. EVALUATION OF MARATHON C-360 HYBRID PROTOTYPE

5.1 Track Testing

The hybrid van was extensively tested at the Transport Canada Motor Vehicle Test Centre (MVTC) in Blainville, Quebec, at the DSMA laboratory using a route laid out around the streets of Mississauga, and in a short in-service test. Several modifications were made to bring the vehicle up to the required standards for use in Ontario.

It was found that operation in ICE mode was not possible unless the vehicle was travelling at constant speed on a level road. The gasoline motor did not have sufficient torque to accelerate the vehicle rapidly enough to be compatible with traffic.

The track tests were conducted during the week of November 23-27, 1981 and consisted of 2 days of performance testing and 2 days of range testing. The results of the performance testing illustrate the effect of the hybrid mode and the electric mode. Table 4 shows average acceleration times to specific speeds along with the maximum speed for each gear in both hybrid and electric modes. Acceleration times were all lower in the hybrid mode.

The use of hybrid mode meant an average increase of 25% in maximum speed for each gear. These results indicate that the hybrid van could be more traffic compatible in hybrid mode than in electric mode. The 2 range tests were done using the SAE J227-a-C cycle, with the range being determined by the ability to meet the cycle acceleration limits of 48 $\pm$ 1.5 km/h within 18 $\pm$ 2 seconds. While the hybrid mode could achieve this easily using only third gear, operation in electric mode barely made the requirement using 2nd, 3rd and 4th gears.

Electric mode range was 7.9 km while hybrid mode range was 65.7 km, but these results should be considered more a measure of the vehicle's ability to meet the J227-a-C cycle rather than an indication of range. The gasoline fuel consumption during the hybrid mode range test was 7.16 litres for a specific fuel consumption of 10.9 l/100 km.

5.2 Street Testing

The street testing near the DSMA laboratory in Mississauga was an attempt to evaluate the range and energy consumption of the hybrid van in a suburban/industrial situation such as a light duty delivery van would experience. A route was laid out encompassing both residential and industrial streets with the DSMA laboratory as the start/finish point. Each lap around the route involved a distance of approximately 15 km and speeds ranging from 40 to 75 km/h with a total of 9 traffic lights and 19 stop signs. The vehicle was driven in a manner representative of a normal delivery truck driver with a minimum of special treatment. The range of the vehicle was defined as the distance at which the battery pack voltage dropped below 84V (1.75V per cell) at a load of

TRANSMISSION GEAR	OPERATING MODE	AVERAGE ACCELERATION TIME (SECONDS)				MAXIMUM SPEED (km/h)
		0-24 km/h	0-32 km/h	0-40 km/h	0-48 km/h	
1	HYBRID	3.4	7.2	--	--	36.1
	ELECTRIC	5.3	--	--	--	29.8
2	HYBRID	3.8	5.4	8.8	16.2	51.7
	ELECTRIC	4.9	8.7	22.6	--	41.3
3	HYBRID	4.9	6.9	9.1	12.7	66.5
	ELECTRIC	6.4	9.2	13.8	24.4	51.4
4	HYBRID	6.5	8.9	11.3	14.6	77.4
	ELECTRIC	8.8	12.1	15.8	21.4	62.1
1-2-3-4	HYBRID	3.6	9.0	12.3	20.1	76.2
	ELECTRIC	6.4	12.7	24.5	35.0	58.7
DOT STANDARDS *		4	6	9	15	--

* U.S. Department of Transportation Safety Standards for utility or commercial purpose electric vehicles.

Table 4 - Performance Test Data for Marathon C-360 Hybrid Prototype

75 A.

The test results showed that hybrid mode operation could more than double the range over electric mode. Range for hybrid mode tests varied between 35.3 km and 39.5 km while the electric mode gave 18.2 km and 18.9 km. In the hybrid mode specific fuel consumption was between 8.94 and 9.57 l/100 km, and specific electricity consumption 0.354 to 0.651 kWh/km. In the electric mode specific consumption was 0.894 to 0.978 kWh/km.

5.3 In-Service Testing

The primary objective of the demonstration phase of the project was to use the hybrid van in a "real world" application. This would provide basic operating data plus an evaluation from a potential user's perspective of the vehicle's operating characteristics and its ability to do the job.

The operator chosen for the demonstration was Mr. Henry Walker, a fleet supervisor with Ontario Hydro (OH). Mr. Walker's position required that he travel extensively to the various OH facilities throughout Toronto and the surrounding regions. His trips were usually less than 50 km. The hybrid van was used on 7 days including 1 day when only electric mode was used. The normal mode of operation was mixed with ICE mode used as often as possible to extend the range and hybrid mode used whenever traffic and road conditions required it. The result was an average usage of 52.1 km per day for hybrid mode. This is substantially greater than the range found during the street testing program and shows the effect of switching to ICE mode during constant speed cruising to extend the range of the vehicle.

The average gasoline consumption over the period was 9.2 l/100 km while the average electrical consumption was 0.414 kWh/km for the days when mixed mode operation was used. By comparison the other vehicles which Mr. Walker frequently uses have fuel consumptions of 5.6 l/100 km to 18.8 l/100 km.

Mr. Walker was favourably impressed with the hybrid van despite its limitations in performance and range. He recognized the prototype nature of the vehicle and felt that the ICE portion of the drivetrain required substantial development along with a better method of control which would optimize the mix of gasoline and electric power automatically leaving the driver free to concentrate on the road.

5.4 General Evaluation

Although the Experimental Hybrid Van performed well for a prototype with no major breakdown in more than 800 km of test driving, there were several problem areas which significantly affected the operation and capabilities of the vehicle. The most serious problem was the performance of the centrifugal clutch. The clutch would engage at a speed substantially below the specified 1100 rpm thus effectively stalling the motor. The "leading shoe" design meant that the clutch would not slip smoothly but tended to grab suddenly. The clutch would frequently not disengage

making gear shifting very difficult.

The gasoline engine was another problem area. The 18 hp Briggs and Stratton engine was designed for use in constant speed applications. In the hybrid van, full throttle acceleration would cause the ICE output to drop off and force the driver to reduce the throttle opening until the motor caught and then "feather" the throttle up to full speed. This significantly reduced the rate of acceleration and hence traffic compatibility of the vehicle.

Several other minor problem areas were also discovered during the test program. Once the driver became accustomed to the vehicle it was possible to overcome the problems to a limited extent and even an inexperienced driver could operate the vehicle after a brief instruction period. Most of the problems experienced were due to the prototype nature of the vehicle rather than fundamental design errors. The hybrid van showed certain improvements over the Seaway fleet such as steering characteristics, chopper control, etc.

The results of the evaluation program indicated that hybrid vehicles could offer improved acceleration, top speed and range over similar all-electric vehicles at the expense of additional weight and a more complicated drivetrain and control system. However, this particular model did not feature unlimited range. While hybrid vehicles could have less long-term potential than all-electrics for petroleum fuel substitution, they could affect more fuel substitution in the short-term through possible ability to satisfy a greater market.

6. EVALUATION OF COMPONENTS

6.1 Description of Static Test Rig

The static test rig, as shown in Figure 5, consisted of a C-360 power train and vehicle frame connected to a jack-shaft incorporating a flywheel and absorber-generator. The power train and road-load simulation were manually operated. The vehicle controls, battery packs, and charger were positioned near the rig. Power was transmitted from the rear axle to the jack-shaft via timing belts. The power generated by the absorber was dissipated through a set of resistors. The level of road-load simulated was controlled by selection of the arrangement of resistors and the absorber field excitation. Only basic instrumentation was installed.

The commissioning of the rig was hampered by vibration problems. These were solved by degree as required during the program, and by the end the rig was operable up to speeds representing 90 km/h. The main problems revolved around flywheel balancing, jack-shaft coupling alignments, rear axle modification, and transmission mounting. Battery and controller cables were upgraded to #1 AWG size.

Testing was conducted throughout the program using the rig in various stages of its development. It was used to investigate problems discovered at the Seaway as well as to test new components. It is a useful tool for development of electric and hybrid vehicle components. Its basic functions and its instrumentation can be expanded to permit more sophisticated evaluations.

6.2 8 hp Baldor Motor Tests

The motor used in the electric C-360 vans was an 8 hp, Class B, DC series-wound motor manufactured by Baldor Electric Company of Fort Smith, Arkansas, U.S.A. The motor cooling tests and development of a better cooling arrangement were undertaken because a motor burn-out was experienced on #148.

Baldor had provided three shaft-mounted cooling fans while Marathon had added an external blower to the motor. It appeared that the fans in this arrangement opposed each other resulting in poor cooling. Four configurations were examined in the tests on the rig, the original 3-fan Baldor arrangement, and the 4-fan Baldor-Marathon arrangement with the blower on or off after the test, and a DSMA 2-fan version.

It was concluded that the 2-fan arrangement could limit the motor temperature rise and that running the blower after motor shut-down could further help. These changes were implemented on all the fleet vehicles. A thermostat and associated circuitry were added to keep the external 12V blower on after a trip if the motor case temperature was above 57^{o}C (135^{o}F). Two of the shaft mounted fans were removed to make the air flow more efficient and the motor case was sealed to force a simple 1-way flow

Figure 5 - Electric and Hybrid Vehicle Static Test Rig

of air inside the motor. There were no burn-outs on the fleet.

A motor was also tested to obtain some performance points under steady state conditions. Supply voltage was not chopped. The results are graphed as a family of curves in Figure 6. The torque varied linearly with current between 70 and 270 amperes. There was 90 in-lb at 70 A and 570 in-lb at 280 A. Efficiency was between 80% and 85% generally.

6.3 Battery Heating System

Tests conducted on vehicle #148 indicated that a serious reduction in range could occur if the battery temperatures were allowed to drop below about 10°C and the literature clearly backed this up. Also, at battery temperatures above 30°C, the batteries could provide increased range. Since the fleet vehicles were to be parked and charged out of doors during winter weather at the Seaway, it was considered imperative that the batteries be heated at nights and on weekends. In order to achieve this, a battery heating system with thermal insulation was designed by DSMA and installed on each fleet vehicle (3).

It consisted of heating elements taped to aluminum sheets and placed below each of the two battery packs. A 365 Watt strip heater element was used below the large pack and a 165 Watt element below the small pack. One inch of styrofoam insulation (R factor = 7) was placed below the heating elements and one half inch (R = 3.5) on the four sides. A control circuit activated both heaters whenever the battery temperature was below 32°C (90°F). The heaters were powered from the grid whenever the vehicle was plugged in.

The system was first installed on the test rig battery pack in the DSMA laboratory. A battery heat run based on 2 charge/discharge cycles per shift showed that the insulated batteries could overheat but it was concluded the Seaway would probably not use the vehicles this heavily.

The effectiveness of the system in extending the vehicle range in cold weather was checked in the range tests reported in section 4.2.2. The results were disappointing in that although the system was effective in maintaining the battery temperatures only a small increase in range was realized. It was observed during operation of the vehicles that in spite of warm batteries and a fully charged battery pack, the vehicles were very sluggish after an over-night soak in sub-zero temperatures. It was concluded that excessive road-load at low temperatures, probably due to the cold lubricating fluids, was responsible. Tests below -5°C were not conducted.

The cold vehicle effect was not present in the range tests on vehicle #148 because the vehicle had been stored in-doors to produce warm batteries. The operation of electric vehicles in cold weather therefore could involve factors beyond battery thermal conditioning to increase the success.

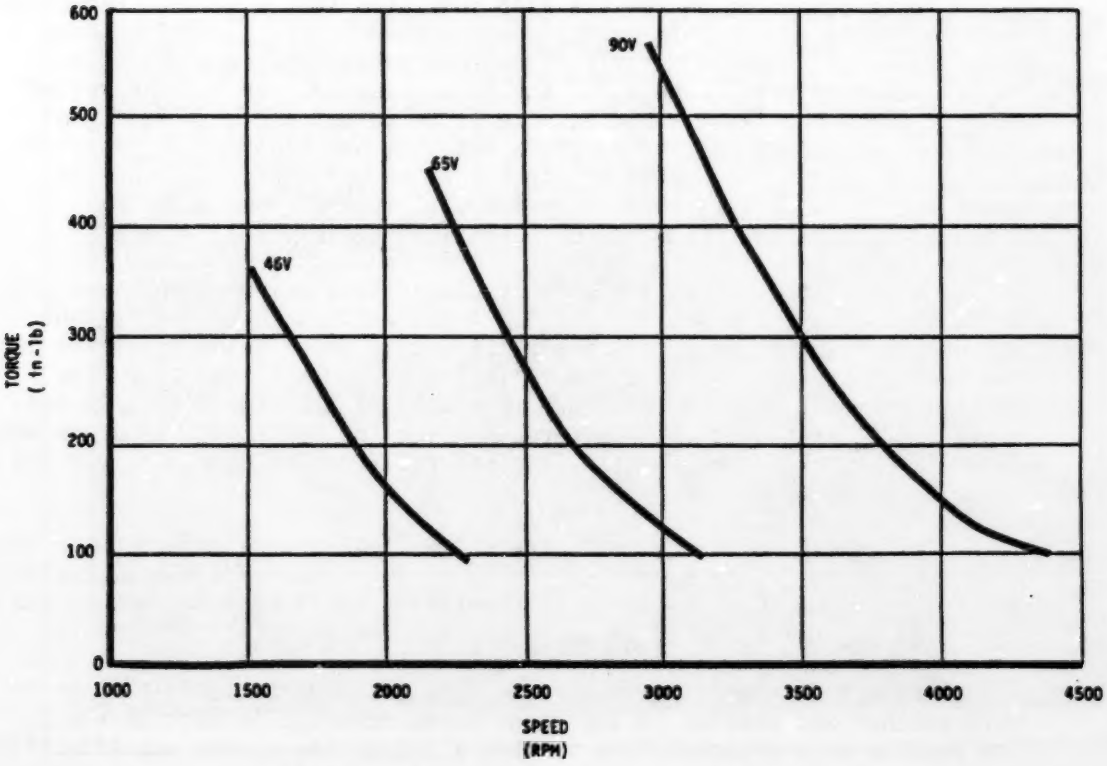

Figure 6 - Speed/Torque Characteristics for Baldor 8 hp Motor

6.4 Batteries

During the program batteries were evaluated directly on the test rig and indirectly in vehicles, but all work was confined to the lead-acid type. Five different models of batteries made by 3 manufacturers in Canada and the U.K. were used.

No life cycle data was obtained, although the original ESB EV-106s were still in the fleet vehicles after the year of demonstration. The EV-106s were used in #148 for the first 4910 km and then removed. However, ESB gave them a good equalization charge and said they had 80% of their life left. EV-106s are rated to provide 75 A for 106 minutes to 1.75V per cell at 27°C (80°F).

It was found that the 6V golf cart batteries, such as the EV-106 and Varta P-125, weren't reliable. Periodically one or two batteries in a pack failed and were replaced with new ones. This was a costly and unanticipated repair item. The batteries' servicing requirements also turned out to be fairly costly with watering and cleaning required every two weeks and connections cleaned and tightened every six weeks.

During the program at least 20 structured range tests were conducted on public roads. All provide commentary on battery capabilities. But not all had the same objectives, and this eventually led to the battery test project on the rig described below. However there were four range tests conducted using the two AM Electrucks which provided a comparison between the Varta P-125s and the ESB EV-106s. The Vartas gave 60% more range though their ampere-hour rating was only 18% greater. It was thought the greater cycle age of the ESBs could have been a factor.

A Chloride sample of a current production tubular plate industrial battery was installed in the AM Electruck around May 1980. This battery was received in advance of the high energy density tubular plate battery sample they provided. This first Chloride battery did not receive a full evaluation and results were inconclusive.

The C-360 hybrid prototype had Varta P-125x batteries which were apparently very similar to the Varta P-125 batteries but were to require less frequent watering.

The high energy density Chloride battery was model #S26Y9 and this sample was brought in from the U.K. and donated to the program for evaluation. It was a very recent design, not yet made in Canada. Chloride management in Canada provided this in response to a competition organized by DSMA during the program out of which the Chloride proposal was selected. An energy density rating of 39 Wh/kg at 42 A was provided.

A series of tests was conducted on the static test rig to generate data on battery energy densities at 75 A and 200 A draws. The 75 A was selected to confirm manufacturers ratings. The 200 A point was used to obtain data where ratings were not provided and because it was a rough average of acceleration and cruising currents in the C-360. The 1.3V/cell cutoff was used. Results were:

- Batteries have a "memory" as it took several exercising cycles to get them up to a constant performance point,
- at the 75 A rate the Vartas lasted 100 minutes instead of 125, and had an energy density of 22 Wh/kg,
- at the 200 A rate the Vartas showed 14 Wh/kg,
- Varta ratings were 38 Wh/kg at 33 A and 31 Wh/kg at 53 A,
- Chlorides showed 27 Wh/kg at the 75 A rate and 19 Wh/kg at the 200 A rate.

The Vartas were older than the Chlorides and had seen more use.

6.5 Drivetrain Components

The road-load simulator was limited initially by a severe vibration within the upper end of the speed range. A similar vibration was experienced in the fleet vehicles and drive-line vibration was the suspended cause.

Marathon provided two new drive-lines which were investigated on the reference vehicle (#311). An accelerometer was used to measure the vibration level as the rear wheels of the vehicle were spun to a high speed and allowed to coast down with motor off. Two tests were conducted on the original drive-line and on each of the two replacements. The original drive-line installation was found to have a run-out of .020" to .050". The two new drive-lines had run-outs of .013" to .051" and .013" to .042" respectively. There were no basic differences between the three drive-lines and the drive-line itself did not appear to be the primary cause of the vibrations. However the vibrations could sometimes be reduced by rotating a yoke 180^{o}. The mounting of the transmission and motor and overall power train alignment require further study since the basic cause of the vibration was not found.

A problem with the transmission was that in an automobile the transmission is very accurately aligned with the motor via the bell-housing and the input shaft to the transmission is supported by a pilot bearing in the flywheel. In the Marathon design, the transmission was only roughly aligned with the motor and the input shaft floated in a bore in the motor shaft. As a result, the transmission gears did not mesh properly causing excessive wear, noise and vibration. Marathon was advised of this and the problem was corrected on the hybrid van. Marathon are planning to revise their design for future production.

6.6 Front-End Alignment

There were many complaints of steering problems and damage to the front suspension geometry. These problems were found to be due to a basic geometry design shortcoming and could not be completely alleviated by re-alignment. Marathon have since re-designed the front end suspension to remove this problem and claim an increased range as one result. The new design has been installed on the fleet vehicles since September 18, 1981 under another TDC program.

6.7 Contactor-Resistor Controller

This controller designed by Marathon provided voltage control to the motor by regulating battery output voltage. The controller utilized three single ended power solenoids model SW89-18 and one double-ended power solenoid model SW112A-17, all made by Albright of the U.K. There was also a power resistor. There were four positions:

i. two battery banks in parallel and resistor used,

ii. same as i. but resistor bypassed,

iii. two battery banks in series and resistor used,

iv. same as iii. but resistor bypassed.

Many circuit failures, involving sufficient heat to melt cables, conductor terminals, and solenoid posts were experienced during operation of the vehicles at the Seaway. On at least 4 of these occasions, the failures appeared to be due to heat generated within the solenoids. Analysis of the heat generated by arcing and contact resistance within the solenoids indicated that the power loss and operating levels were some three times the manufacturer's recommended limit. The cables and terminals were also judged to be of too low a power rating.

The controller provided essentially 100% efficient power transfer for most cruising, but may have put other components into inefficient regions. The resistor, while creating inefficiency when used, was used so little that the controller's overall efficiency was probably very high. The controller's jerky characteristics aroused complaints. under a follow-on program the vehicles were retrofitted with a chopper controller and heavier cables.

While choppers are becoming increasingly popular due to their smoothness of control, resistor/contactor controllers will not necessarily disappear. The concept has been used for 100 years due to its simplicity. A carefully designed controller with an optimum value of resistor could still prove to be an adequate and acceptable method of motor speed control on electric or hybrid vehicles. Alternatively, it could control the field or armature only of a shunt motor.

6.8 PMC Chopper Test

A chopper controller manufactured by PMC Ltd. of Berkley, California, Model DCC96B, having a 4000 Hz chop frequency, 400 A current limit and transistor switching was tested. This is the same type installed in the Hybrid Van, is used by Marathon in their current production models, and was retrofitted to the Seaway fleet after September 18, 1981.

The PMC chopper was installed on the test rig. Operation was much smoother and more controlable than with the original 4 stage contactor controller. Because of the 400 A current limit damaging current/torque peaks were avoided.

Motor voltage and current waveforms were examined and a scope photo is shown in Figure 7. The current flowing in the off portion of the cycle is due to the free-wheeling diode in the chopper. Note the severe oscillations which could cause motor inefficiencies or even overheating.

6.9 Lester Charger

The charger tested was manufactured by Lester Electrical of Nebraska, Inc. and identified as Model 9462, and Type 12/96LCR25-5ET. This was a full-wave rectifier ferro-resonant type of charger with internal electronics to switch off the input AC power supply when the batteries are deemed to be fully charged. The charger has a 12V output as well as the 96V output, both operating off secondary windings on the same transformer. This was an old model of charger which has been largely replaced with newer SCR types. Marathon used this on the Seaway fleet, the hybrid prototype, and the rig because it was small enough to go on-board and was low-priced.

Charger output wave forms were seen to have a fairly simple voltage with about 2% ripple and the current coming in bursts. There was current present for short periods every 1/120 of a second and current levels peaked at about 4 times the average value.

Tests results from a typical charging cycle are shown in Figure 8. Varta P-125s were used and the test lasted until the charger shut itself off. It was concluded that approximations could be made and thus for the output side:

$$P_{avg} = V_{avg}\, I_{avg}$$

where

$$P_{avg} = \frac{\text{Energy in a Period}}{\text{Time for a Period}}$$

Pavg for this test is plotted as well and the energy output was calculated at 17 kWh.

A test was conducted to determine the hydrogen levels that might be created in a C-360 during charging. The most gassing was seen to be during equalization. Probes were placed below the floor deck (just above the batteries) and just below the ceiling. The hydrogen did not exceed 18% of the lower explosive limit and there was thus no hazard. However, any changes to the floor seals or door seals due to design or vehicle deterioriation could call for further testing.

Specific gravity measurements taken on the fleet vehicles during the demonstration showed high levels of charge and little scatter between cells during the first six months. After that charge levels seemed to be decreasing and the variation between cells increasing. It was concluded that the batteries were starting to deteriorate and that the charger was poor at equalizing.

6.10 Oil Level/Viscosity Testing

Efficiency of an automotive drive-train is significantly affected

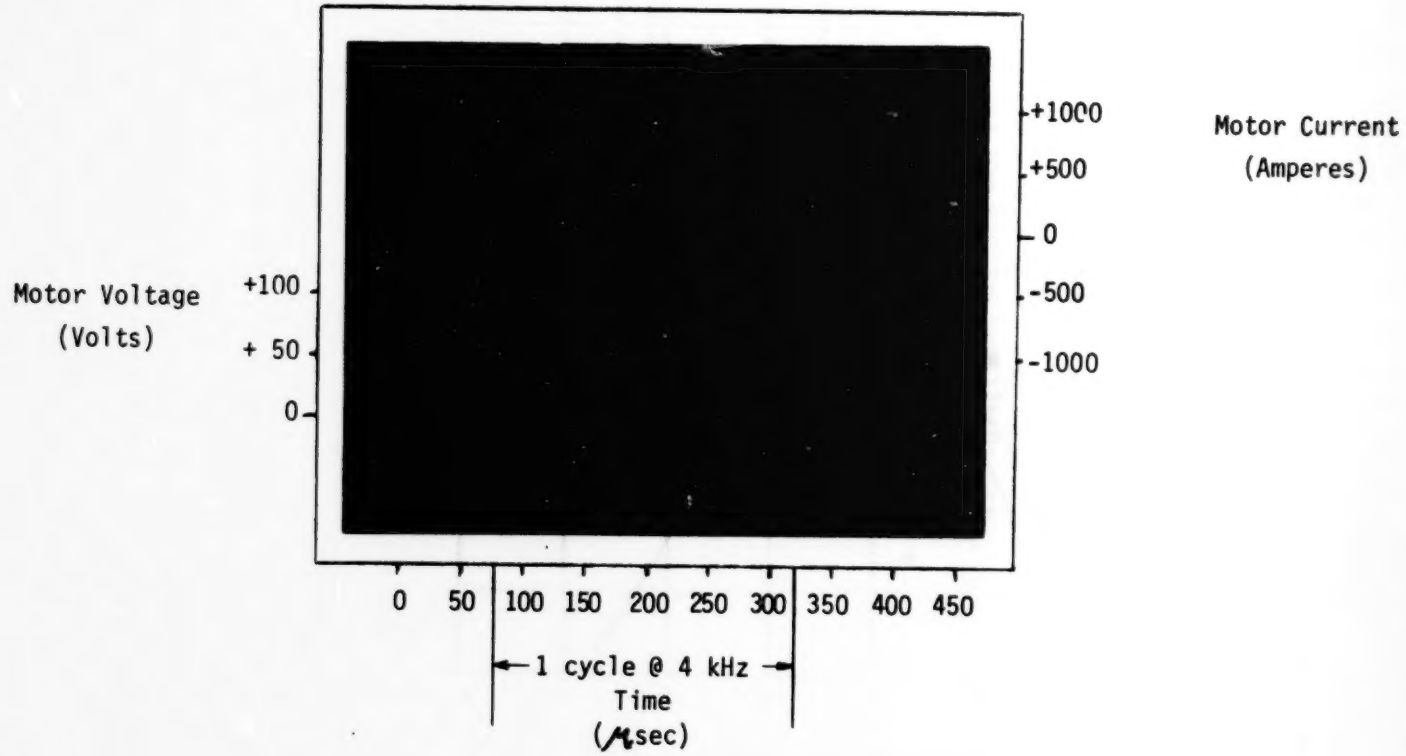

Figure 7 - PMC Chopper Output Waveforms - Series Motor, No Reactor

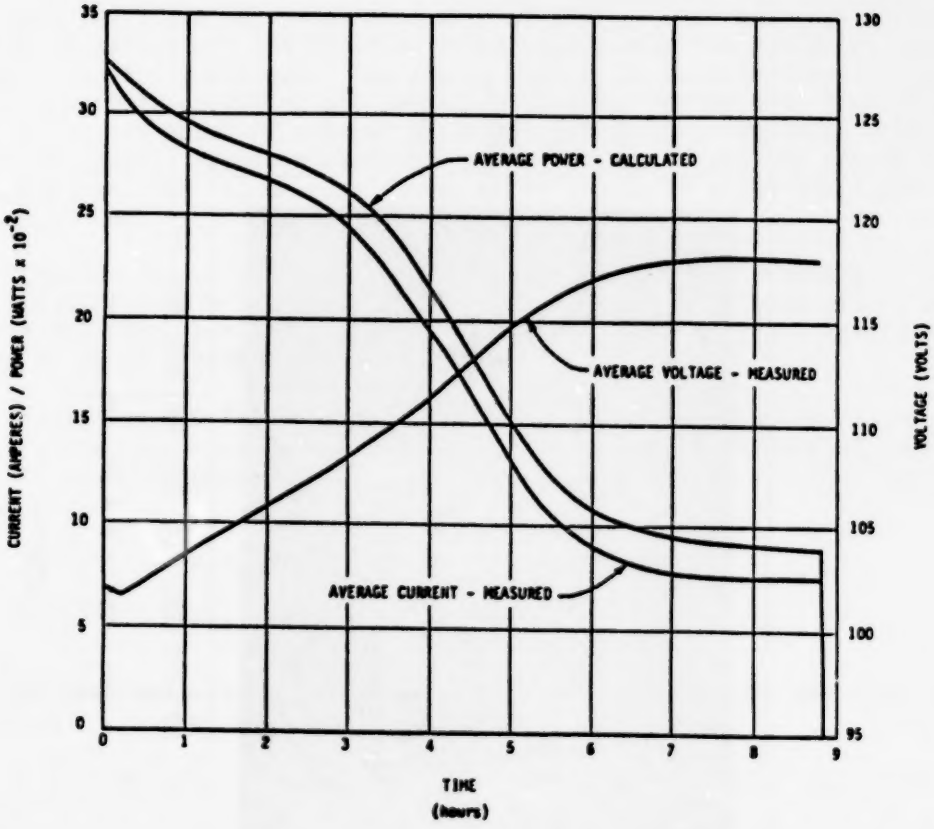

Figure 8 - Lester Charger Output Characteristics

by the type and amount of lubricant used. ICE vehicles must be capable of cruising for lengthy periods at high speed without overheating the lubricant. EVs do not have such severe conditions.

Automatic transmission fluid (ATF) was chosen as an alternative lubricant to the standard SAE EP 90 gear oil. To determine the feasibility of the ATF lubricant, a simple constant speed test was developed for the test rig with the temperature of the oil being the determining factor. The testing indicated that ATF runs substantially cooler than EP 90. Reducing the quantity of EP 90 gear oil had no significant effect upon the peak temperature.

The study showed that the use of ATF in EV transmissions, and differentials was an improvement over EP 90 gear oil although no quantitative data was obtained on energy losses in transmissions and differentials under the various conditions tested. Thus it seems in order that ATF be tried in a C-360 and long-term effects in terms of leakage and gear wear be determined.

7. THEORETICAL STUDIES

7.1 Configuration and Operation Strategy

The ELVEC program developed by Jet Propulsion Laboratory in the U.S.A. was used to perform this parametric study. Program limitations were such that the hybrid vehicle described in section 2.3 could not be simulated exactly, and so general cases were studied with attention being directed toward the effect of component matching and the selection of operating strategies.

The driving cycle selected was a DSMA modification of the SAE J227a C cycle, whereby the acceleration time was lengthened by 12 seconds and the idle time shortened by 12 seconds. It was designated as J227a CM. The configurations studied were the pure electric vehicle, the pure gasoline vehicle, the parallel hybrid vehicle and the series hybrid vehicle.

The following method was used for comparing gasoline, HVs and EVs with regard to the technical factors of range and fuel consumption. Each particular vehicle simulation was plotted on a graph of range versus fuel consumed during a range test (see Figure 9). Range was considered as the "benefit" while the fuel consumed the "penalty" incurred for the increase in range. Evs were plotted along the horizontal axis since they did not consume fuel. (Effect of petroleum fuelled heater/defrosters was not studied.) Gasoline vehicles have a specific fuel consumption as is represented by the sloping line in the graph. HVs may have operating points anywhere within the diagram, even above the line for a gasoline vehicle. In terms of preferred operating point the top left corner is the worst point while the bottom right is the best.

The results of 32 simulations are shown in Figure 9. Note the range of the electric vehicles (Points 1, 2 and 3). The results indicated that design of a hybrid vehicle was a complex procedure involving optimization of many parameters; these parameters are non-linear and sometimes discontinuous in nature. The sensitivity to some parameters such as driving cycle may warrant the customizing of each hybrid vehicle to a customer's needs. For the conditions examined there was an optimum heat engine size for each hybrid design.

The modelling of components within ELVEC was found to be simplistic and the options rather limited, but the potential for increasing the range and thus marketability of the C-360 through hybridization was evident. The simulations indicated a potential for fuel substitution, but to achieve that potential vehicle designs would have to be optimized to their particular application.

7.2 Annual Fuel Substitution Based on Market Penetration

An earlier study in the spring of 1980 examined the energy consumed by a number of electric and hybrid vehicle configurations in the performance of a defined mission profile using ELVEC. The mission pro-

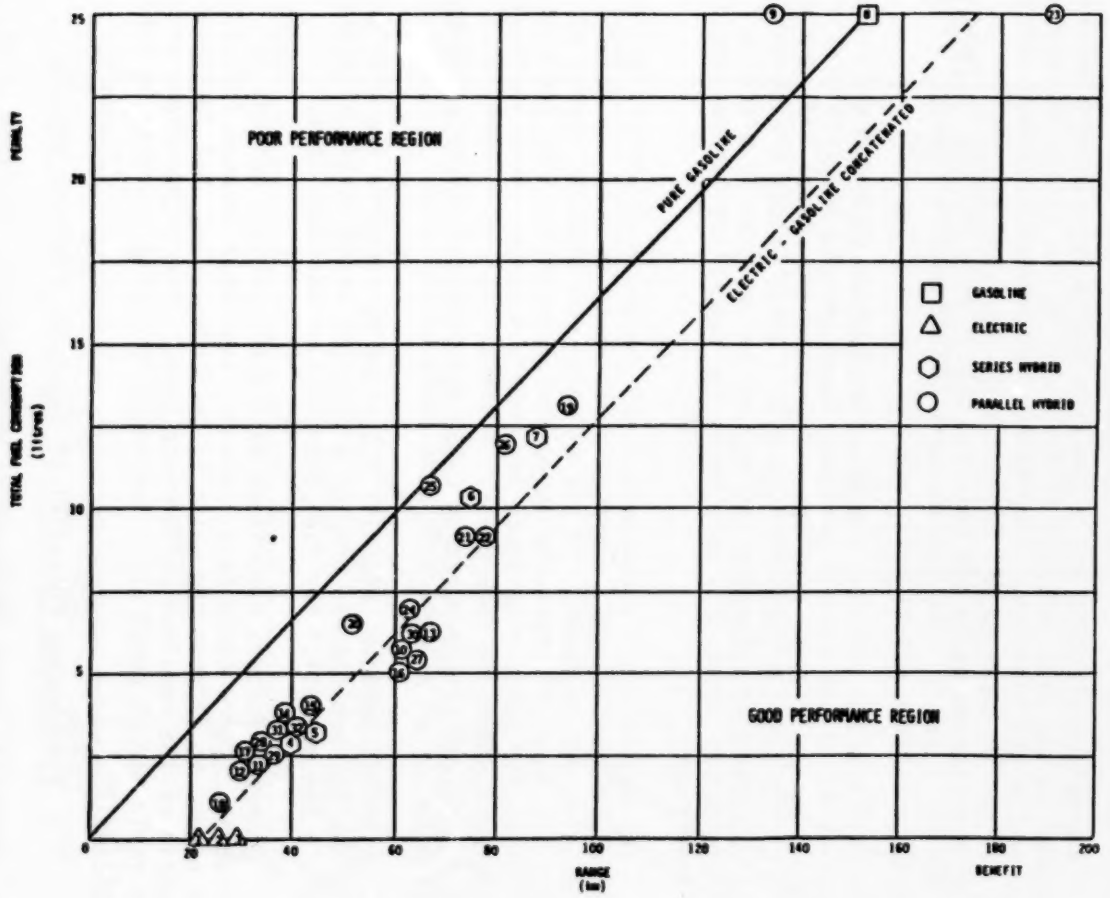

Figure 9 - Range and Fuel Consumption for Various Strategy and Hardware Size Configurations without Cabin Heating

file selected included a mixture of the SAE J227a B, C, and D driving cycles plus a period under freeway conditions and represented typical van service based on the results of a literature survey. The results were manually combined to derive the annual petroleum consumption for the level of market penetration permitted by the performance of the vehicle. The fuel for the electrics, and the hybrids in an electric mode, was that required on an annual basis for cabin heating.

A baseline electric and a baseline hybrid vehicle were defined by upgrading the 1979 versions of the C-360 to the status of improved state-of-the-art vehicles. Progressive improvements to these vehicles were defined in Improved All Electrics #1, 2, 3 and 4. Similarly, progressive improvements to the baseline hybrid were defined in Improved Hybrids #1, 2 and 3. The hybrids were all parallel strategy. Finally a gasoline vehicle was defined.

Only the ICE vehicle, the improved hybrids #2 and 3 and improved electrics #2, 3 and 4 could meet the speed, range, and accelerations required by the mission profiles. The estimated annual fuel consumption for the vehicles are shown in Figure 10. These values are based on optimized component efficiencies and may not be realized in practice. They are intended to serve only as a basis for comparison between the different configurations.

The maximum fuel substitution will be achieved with an all-electric vehicle with sufficiently improved performance to meet the majority of the mission requirements. If all of these requirements cannot be met within the level of improvements currently feasible, then the substitution of an ICE vehicle on those days where a longer range is required is the most effective compromise. A substantial improvement over the 1979 technology of the Marathon C-360 was required before any significant penetration in an all-electric mode could be achieved.

A hybrid vehicle, with its ICE sized to complete the missions for which the ICE vehicle was used as a back-up, was a viable alternative although the potential for fuel substitution was much less.

Economic factors associated with these vehicle options were not considered. There could be a trade-off available between the cost and time needed to improve the basic EV performance and that for developing a hybrid of the required performance level. The hybrid might provide a more rapid market penetration and hence, an early increase in fuel substitution.

7.3 Performance Potential of the C-360 Electric Vehicle

Potential range improvements which could be realized on the C-360 are: higher energy density batteries (20%), chopper (5%), tires (10%), front wheel drive with transaxle (15%), regenerative braking (15%), body aerodynamics (10%), and "smart" control (25%). These improvements could increase the range from about 25 km as measured at the Seaway to 65 km. The adoption of a "smart" control system implies the use of a control system as is shown in Figure 11. All of the components shown, except for the dedicated computer, are available or could be obtained under the

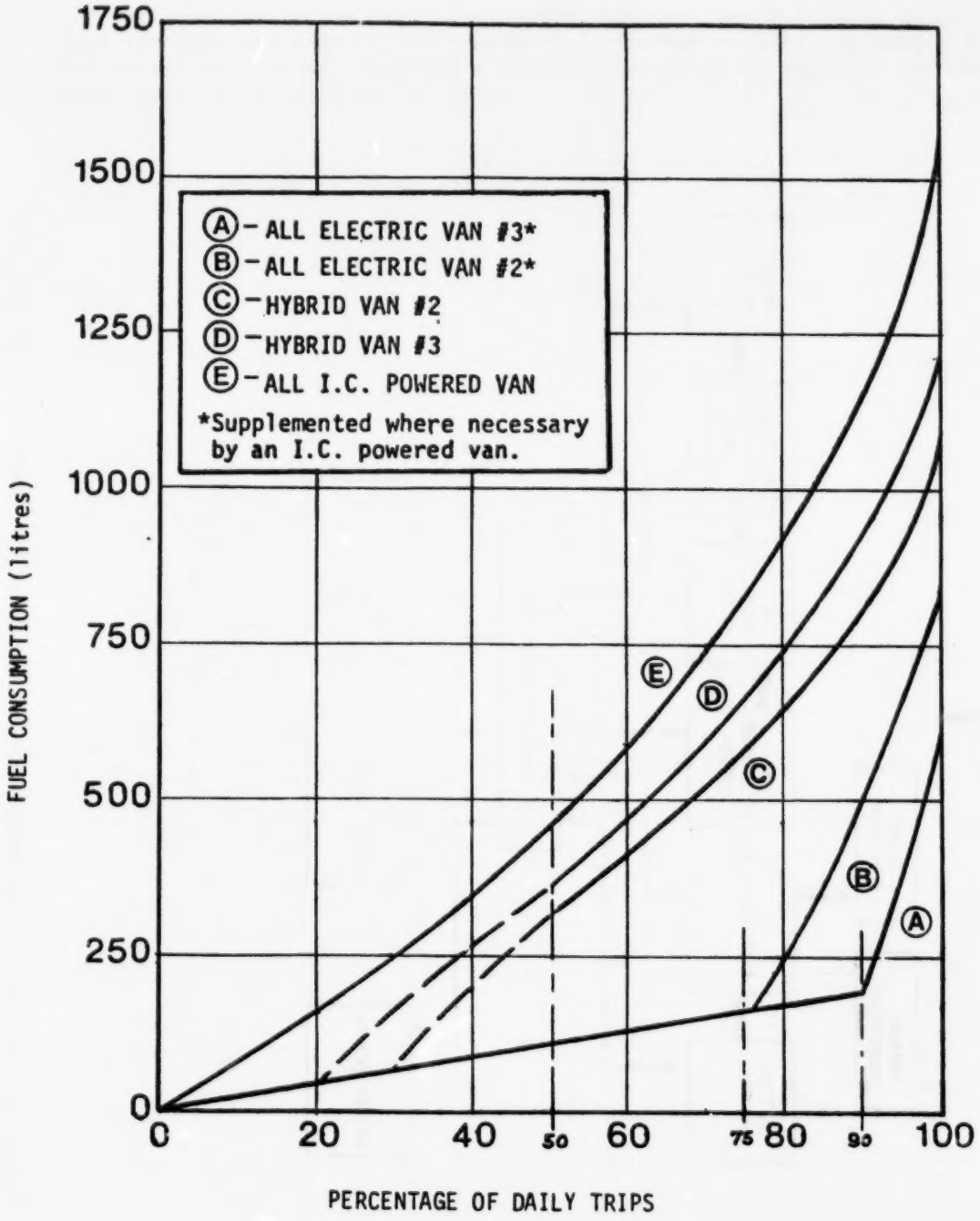

Figure 10 - General Delivery Vans - Fuel Consumption With Cabin Heating Throughout a Single Year

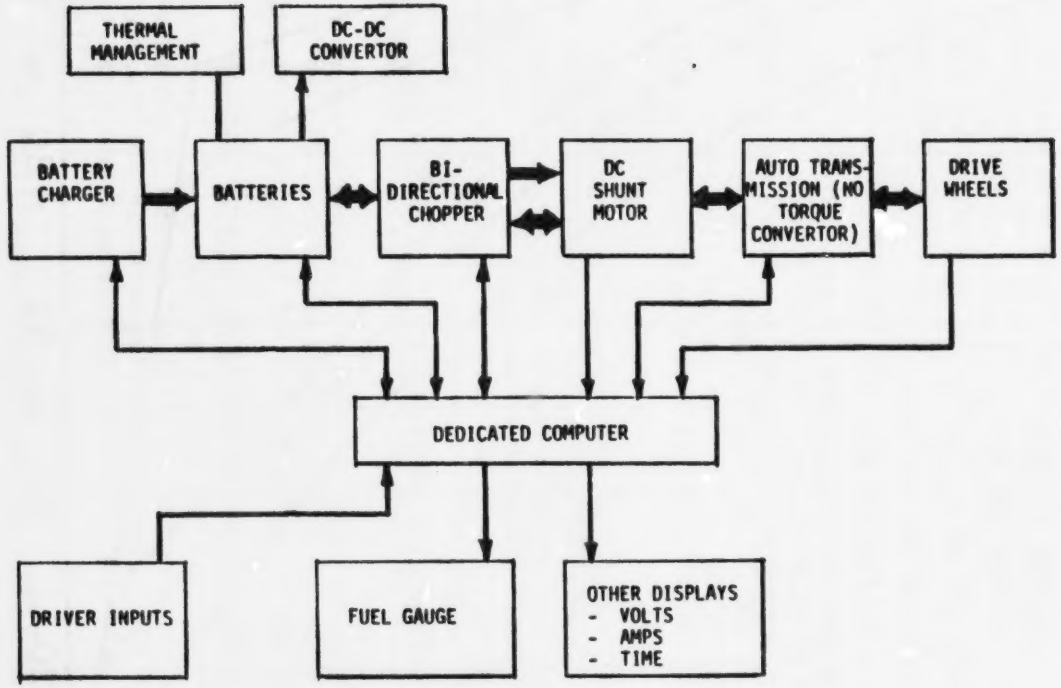

Figure 11 - Microprocessor Based Control Strategy for Upgraded C-360

current level of technology. The system, however, would require development for adequate matching of components. Further studies are needed to define the driving strategy and control characteristics required for the development of a smart power system controller.

8. DISCUSSION AND CONCLUSIONS

8.1 Marathon C-360 Electric Van

The Marathon C-360 demonstrated, during a year of service at the Seaway, that it could successfully replace internal combustion engine vehicles in a real-world situation. The application was not demanding in terms of the range and speed requirements, but the vehicles were often loaded 15% higher than their rated gross vehicle weight and occasionally to as much as 25% higher. They were operated, parked and charged outdoors in temperatures ranging from +34°C to -22°C. The vehicles carried out all of their assigned duties but with some breakdowns experienced. They logged a total of 18,248 km during the year with an average daily use of 14 km per vehicle. The vehicles were found to be capable of sustaining speeds up to 60 km/h under the Seaway operating conditions and were driven at this maximum speed whenever traffic conditions permitted. Acceleration levels were good and there were no complaints on compatibility with other traffic. There were no apparent problems in negotiating grades to 6%. The daily range available varied between 15 km and 25 km and this could be extended to 50 km with charging between trips. It was found that outfitting a standard C-360 vehicle to suit a specific application involved a considerable design effort and additional hardware. The resulting weight penalty significantly lowered the performance of the vehicle.

The vehicles assigned to duty cycles were available for use 94% of the time with the spare vehicle filling in during the periods of unserviceability. The vehicles required about 2 man-hours per vehicle per week for maintenance and repairs. The reliability record of the vehicle therefore was somewhat lower than that of a conventional ICE van. Many of the faults were corrected within a matter of hours and resulted in very little down-time. The vehicles were relatively easy to maintain but the service of highly skilled technicians and engineers were required to diagnose and execute rapid repairs. The somewhat poor mean distance between failures of 162 km was primarily due to design defects. Some improvements were introduced during the program and others have been installed on the vehicles since the year of demonstration. The reliability of the vehicles has not been demonstrated to the point where they can be recommended for general use. Further field experience is required to develop this reliability but it should only be gained in fleet service with adequate technical support, to ensure proper maintenance and feedback on problems to the manufacturer. This is important because the infrastructure required to support electric vehicles is not currently in place.

In a large sense the evaluation of the C-360 electric becomes a series of detailed component evaluations. Marathon must buy many components which are not ideal for their purpose. In some cases minor modifications are possible and in others not. Some components like tires, headlights, etc., function normally and arouse no notice. Others like the charger, batteries, motor, and front end received notice and further

testing due to problems and have been discussed earlier. Marathon can continue to adopt improved components as they come along but this will never achieve quite the performance possible through system studies and matched, customized components.

The Marathon C-360 was initially designed to meet the requirements specified by the United States Postal Service (USPS) and an order for 10 vehicles has been received. The Canadian Post Office, Ontario Hydro and other Canadian organizations are also interested in acquiring C-360s for evaluation. The demonstration program at the Seaway has helped Marathon to remain in contention for these supply contracts through the increased visibility of their product. It has provided proof that the C-360 can fulfil a useful role and that they have the support of the Canadian government. This program has accelerated the C-360 development through the early disclosure of the design defects noted above and the development of viable solutions. Under the stimulus of this program, market pressures and their own continuing efforts, Marathon have developed or introduced major improvements on their more recent models such as a new front-end suspension geometry, a chopper controller, heavier electrical wiring and connectors, a higher rated motor, a roof vent, a new windshield arrangement, improved sealing around doors and windows, and higher energy density batteries.

As the only electric vehicle currently produced and marketed in Canada, the Marathon C-360 represents the present status of Canadian EV technology. Its performance compares favourably with the production models of small companies in other countries. But its performance is significantly behind those prototypes produced under big-budget government programs and prototypes by Lucas, Fiat, General Motors, etc. The C-360 appeared to be in the early stages of development and showed potential for adequate and reliable service in a segment of the light duty van market.

8.2 Prototype Marathon C-360 Hybrid Van

During the 800 km of shakedown and testing of this vehicle, some conclusions were evident. The vehicle was functional but difficult to drive. The vehicle had greater acceleration and top speed capabilities than the C-360 electric and thus blended with traffic better. It was possible to operate in any of three modes - electric, gasoline, and hybrid. But due to the low horsepower of the motor and the type of clutch used the gasoline mode did not provide adequate acceleration for operation in normal traffic. The vehicle is not considered to be ready for commercial use.

The use of hybrid mode increased the range by at least 100% over electric mode operation. Switching to gasoline mode during constant speed cruising could further increase the range to more than 3 times the 18-20 km obtained when only battery power was used.

While the gasoline consumption, at 9.2 l/100 km was not outstanding, it is better than what some types and sizes of conventional vehicles would use in the same application. Electricity consumption averaged 0.41 kWh/km in hybrid mode and 0.8 - 0.9 kWh/km in electric

mode keeping the operating cost for energy in the same region as an ICE Fairmont and lower than an ICE pick-up truck.

The increased range of hybrid vehicles over all-electrics means they have a greater potential for commercialization in the short-term and hence, a greater potential for petroleum fuel substitution. However, at the present, hybrid vehicle development in Canada is a few years behind electric vehicle development and the electric side of hybrids needs as much improvement as the gasoline/controls side.

8.3 Components

Comments on components vs complete vehicles require the creation of a somewhat arbitrary boundary. In the previous two sections, it was hard to evaluate vehicles without talking about components but in this section components are discussed specifically. No components were evaluated exhaustively although some received considerable attention. Others just got a "quick look".

The 8 hp Baldor motor proved to provide adequate, if not optimized, performance to the C-360 electric, after some overheating problems were resolved. The battery heating system installed on each vehicle kept the battery temperatures well above the ambient in cold weather but comparative range tests led to the conclusion that EV winter performance suffered from more than just cold batteries. The mechanical portions of the drive train had higher losses when cold.

During the course of the program a great deal was learned about batteries. Tests showed that battery energy density was very much a function of discharge rate. It was also related to recent use history. No clear data was obtained to compare energy density of various model and brands. No life cycle data was obtained. From the field experience the biggest lesson was that batteries require a few hours of maintenance each month to keep them clean and watered. Reliability of batteries was poor, with one or two in a pack needing replacement rather frequently. The fleet vehicle's batteries, ESB EV-106s, have a lower amp-hour rating (other factors like nominal voltage and weight per 3 cell monoblock being constant) than others which were available like the Varta P-125.

The C-360 electric had vibration problems which were not fully resolved. Studies with drive-lines showed that vibration could sometimes be reduced by rotating a yoke 180^{0}. The front ends were found to have an incorrect design geometry causing poor steering characteristics but this fault has now been rectified by Marathon.

The resistor/contactor controller design caused many failures in service through overheating. It also had a jerky driving characteristic which led to poor driver acceptance. The principle is not necessarily to be abandoned but this implementation was poor and has since been replaced by a chopper.

Experiments with a PMC chopper showed it to have very smooth functioning but the output waveform raised questions about motor

temperature and efficiencies. The Lester charger model used by Marathon was examined. It was found to provide inadequate charge equalizing in field service. Its controls were rather elementary ard it needs to be used carefully in terms of the voltage supplied to it. Experiments performed on the test rig regarding lubricants in the transmission and differential showed little potential for improved efficiencies due to lower lubricant levels but some potential through use of a lighter fluid such as automatic transmission fluid.

In terms of components the need is two-fold. Firstly, some components need to be updated to the latest state-of-the-art. Secondly, and rather a bigger issue is the matching of components. Serious studies are needed to make the components compatible so the whole drive-train has optimized efficiency. By and large these components could be developed and manufactured in Canada, were there a sufficient market.

8.4 Alternative Configurations

Theoretical studies provided more insight as to how light-duty vans might perform. Both electrics and hybrids were examined using the ELVEC simulation program. Improvements looked at were generally of a near-term nature, involving basic engineering and system studies.

One study involved urban driving below 48 km/h (30 m/h) and explored the range and fuel consumption of 32 different designs and control strategies. Ranges between 22 and 191 km were obtained. It was evident hybrids had greater range and had the potential to capture a larger market than EVs in the near term. Clearly the optimization of a hybrid design was by no means straightforward. As well as the great number of design combinations there were many possible operating strategies and real-world use requirements.

Annual fuel savings possible with various near to medium term alternative vehicle configurations were examined under a combined urban and freeway driving cycle. Attention in this study was on the hardware choices available for EVs and HVs now and in the near future as opposed to operating strategy choices. The best alternative was a somewhat improved Ev and the use of an ICE vehicle on the days (10%) when the EV had inadequate range. The hybrid cases studied showed potential for less fuel consumption than an ICE van but ranked lower than the EVs. Economic factors and development times were not included in the analysis. Hybrids might achieve faster market penetration but the many uncertainties involved mitigate against halting the development of either EVs or HVs.

The 1980 technology C-360 could have its range increased by 150% through use of current technology batteries, a chopper, future types of tires, a transaxle, a microprocessor based drive-train controller, use of regenerative braking, and possible improved aerodynamics. Some of these changes are easier than others, but the compounded effect, although costly to achieve, would put the vehicle much closer to the performance class of something like the Lucas/Bedford van.

9. RECOMMENDATIONS

1. Service and performance data were recorded during the year of the demonstration. However, the seven C-360s were modified during the demonstration by DSMA, and by Marathon afterwards. It would be useful to record and evaluate the benefit of these changes. Furthermore, as the service life of the batteries and other components had not been fully exhausted, a more accurate assessment of their service life could be made by extending the test period. A program of continued fleet use at the Seaway is recommended. Performance should be evaluated through periodic testing as during the first year of demonstration. This would ensure continuity, capitalizing on baseline data and detecting deterioration of specific components. All results should be reported.

2. Further field experience is needed to accelerate vehicle development and the growth of support infrastructure. The Seaway application is one special case and a wider variety of vehicle roles must be explored. More EV demonstrations are therefore recommended with the fleets being given careful servicing. A facility or agency in each area of major EV deployment should be established to facilitate repairs to vehicles and recording and reporting of problems. This facility must be independent of the manufacturer although there would be liaison. Another part of this wider demonstration program would be a continuing R & D effort aimed at improving reliability of the less exotic components.

3. Improved EV components will not be developed through market pressure until there are enough electric vehicles on the road to justify a significant production. This type of market penetration, however, will not occur until improved EV components are available to increase current EV performance and reliability. This is the type of chicken-and-egg situation which normally is resolved through government action. It is recommended therefore that a series of design competitions be sponsored similar to the improved battery competition which was conducted as part of this program. Design competitions for improved EV components should be directed towards a specific vehicle and evaluated on the road in that vehicle. Otherwise the component might turn out to be an orphan with no particular application or market potential. The demonstration programs should define the basic requirements and be used to qualify the resulting components.

4. It is recommended that the short term priority in the ongoing development of the C-360 electric be the improvement of reliability. More attention should be given to human engineering for the sake of driver acceptance. Quantum improvements in the basic parameter of range performance are probably beyond Marathon's R & D budget.

5. Any significant improvement in performance, such as that indicated by the improved electric van defined in section 7.3, would require

a major commitment of funds. A small company in a youthful industry would find it very difficult to make such a commitment. There is an opportunity, however, to seize a major potential market ahead of the competition with such a vehicle but the costs are immediate and the payoff in the future. Serious consideration should be given for a joint effort between government and industry to develop such a vehicle.

6. It is recommended that a computer simulation program be developed and supported in Canada, suited to the particular needs of Canadian users. In using presently available programs, the user may not get all of the options he desires. Also, with some proprietary programs, the cost of gaining access to the program may be prohibitive. A program which concentrated on the design of hybrid or electric vehicles, rather than optimizing hardware size for a number of given vehicle designs, would be more beneficial. Such a program would give more control over vehicle configuration, control hardware, operating strategy, and component characteristics. Because of the diverse interests of the potential users, the program would have to be versatile. Careful development of a user oriented program, using modularized components, would cater to the needs of a wide range of Canadian interests such as universities, vehicle manufacturers, government departments and fleet owners. This program could be expandable and portable to any major computer system.

7. The prototype hybrid vehicle tested requires drive train design improvements. Indeed the electric vehicle design that served as a base is significantly behind the state-of-the-art. A highly professional approach is required. The design, fabrication and testing in Canada, of a thoroughly engineered hybrid vehicle is recommended. The starting point would be detailed modelling with the computer program mentioned above. The program outputs would serve as the design guide for components, control systems, etc. The control system should properly match the second-by-second functioning of drive train components. A prototype should be built and subjected to very structured testing on a track. This would be followed by street testing and in-service trials to measure the achievements in the design and its acceptability in the real-world. The in-service testing could be closely monitored but the rigors of the user's application would still be brought into play.

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